Using GIS to assess the potential of crop residues for energy generation in Kenya

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Abstract

Crop residues can make a significant contribution to the energy sector in Kenya. The purpose of this study was to identify the availability and spatial distribution of crop residues and their energy potential through the creation of a Geographical Information System (GIS) model. This information is important to the successful utilisation of these residues. In addition, a GIS tool was created that automates the resource estimation process for the purpose of identifying potential biomass energy plant sites.

This study was conducted considering six provinces: Rift Valley, Western, Nyanza, Eastern, Central and Coast. The Rift Valley Province was selected as the case study for model tool creation and the crops considered in the study were maize, wheat, rice and sugarcane. The study was a quantitative one entailing the collection of secondary data in the form of crop production statistics and spatial data which comprised population, land use and road shape files and analysis using GIS. Residues to Product Ratios were used to estimate the amount of crop residues while Lower Heating Values assessed the energy potential. Moreover, ArcGIS Model Builder was used to create the GIS model tool for the feasibility of a potential biomass energy plant.

The results of this study indicated the amount of crop residues that can be generated in Kenya to be about 7,384,600 tonnes with an energy potential of approximately 124,300 TJ/year. Rift Valley Province was found to have the highest residue generation of about 3,866,000 tonnes with a corresponding energy potential of about 64,800 TJ/year. The GIS model showed that the Rift Valley Province and Uasin Gishu, Trans Nzoia, and Nandi districts all had the potential for high residue generation resulting from their high agricultural production and high yields. The modelling tool was also able to demonstrate the increase in the amount of crop residues that can be collected using different radii around a potential biomass plant.

The main conclusion was that crop residues have a high potential for energy generation in Kenya. In addition, a GIS model tool was created for Rift Valley Province which can be transferred to any other region, in order for the local energy planners to supply the model with their own parameters to obtain locally based results.

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Chapter 1 Introduction

Globally, biomass has been acknowledged as a positive alternative source of energy because it is renewable, cheaper, readily available and CO_2 neutral. Unlike other renewable energy sources such as solar and wind, biomass can be converted into various fuel forms (liquid, solid and gas) through many biomass conversion technologies. It is not only suitable for heat and electricity generation, but also for transportation fuels. Several biomass technologies have been mentioned as being viable in Kenya. These include: electricity generation through direct combustion or gasification; briquetting; biogas generation; generation of pyrolytic oil for vehicle fuel; and methanol and ethanol conversion for internal combustion engines (Nzila et al., 2010; K. Senelwa & Sims, 1999; Wamukonya & Jenkins, 1995). However, the use of biomass resources in most developing countries, including Kenya, is restricted to cooking, heating and lighting (Janssen & Rutz, 2012; Sudha & Ravindranath, 1999). Negative effects of this kind of biomass utilization are emissions and low efficiencies.

Biomass resources account for 76.9% of energy in Kenya (IEA, 2010) and amongst these resources, fuel wood has been the main source of energy for 60% of the rural population (Karekezi, Kimani, et al., 2008). However, the recent decline in fuel wood resources has led to a shift towards the utilisation of crop residues for energy generation. The potential in utilising these crop residues for energy generation, including the amounts available and their respective energy potentials has been well documented for Kenya and most African nations by various studies (Cooper & Laing, 2007; Jekayinfa & Scholz, 2009; Jingura & Matengaifa, 2008). However, the location and distribution of these residues have not been available and lack of information on the geographical location of these crop residues has been the main reason hindering the development of biomass conversion technologies in Kenya (Dasappa, 2011). Knowing the geographical location of crop residues is essential for their successful utilisation as it assists in the identification of potential sites for biomass power plants (Chanthunyagarn et al., 2004; Voivontas et al., 2001). It would therefore be ideal to conduct research to identify the spatial location of this resource so as to provide for advances in the way these residues are being utilised.

The spatial distribution of the biomass resource has increased the interest of researchers in utilising Geographical Information Systems (GIS) for biomass assessments. GIS is a computer-based tool designed for capturing, storing, verifying, incorporating, manipulating, scrutinizing and displaying information associated with locations on the earth's surface. The main characteristic of GIS is its ability to locate information geographically. This tool is important because it facilitates exploration of spatial data and can be used successfully to create multiple layers of information (Dagnall & Pegg, 2000). In addition, GIS can be used to create tools which automate processes.

Globally, GIS has been utilised in various studies to assess the potential of agricultural crop residues for energy generation (Singh et al., 2008, 2011; Voivontas et al., 2001). In these studies, examples of typical crops considered are maize, wheat, rice, millet, sugarcane, sorghum and oats. Results have been presented as maps showing areas with high residue production. This information has guided the identification of potential sites of biomass plants in various studies (Shi et al., 2008; Singh et al., 2011; Voivontas et al., 2001). In Africa, studies utilising GIS for crop residue assessment are limited. One such study was conducted in Liberia where the amount of crop residues was estimated for each county and as a result the spatial distribution of these residues was presented (Milbrandt, 2009). However, possible locations of biomass power plants were not identified. In most of the GIS studies reviewed, none of them presented a tool that automates the crop residue biomass and identifies potential sites for biomass plants. In addition to presenting the spatial distribution of crop residues in Kenya, this study aims to fill this knowledge gap.

Crop residues are the focus of this study because Kenya is an agricultural country and plenty of residues are generated every year which are left in the field to decompose or are burnt. Utilising these residues for energy production will also provide economic benefits to the farmers. Crops chosen for evaluation were maize, wheat, rice and sugarcane. The reason for their selection was that they are the main crops grown in Kenya and are also mentioned as having high residue potential ("Cereals: Kenya," 2011; Lal, 2004). Because these residues are mainly distributed in rural areas, their efficient utilisation will provide clean energy to the households currently relying on traditional energy forms. Only 3 % of rural households have access to electricity in Kenya (OECD, 2010; Osawa, 2004).

Even though various modern conversion technologies have been mentioned as being able to convert crop residues into clean energy forms in Kenya, these residues are still being utilised traditionally. Identifying the availability and the spatial distribution of these biomass resources should lead to a shift from traditional to modern utilisation.

1.1 Overall research aim and individual research objectives

The aim of this study was to provide information on the availability and geographical distribution of crop residues so as to facilitate their utilization using available modern biomass conversion technologies. The study was conducted through the collection of secondary data and analysis in GIS. The research focused on residue assessment at district level in Kenya.

The following objectives are the key to the achievement of the above aim.

Objectives

1. To estimate the amount of crop residues generated and their energy potential in Kenya using GIS. This assessment was conducted for six provinces in Kenya which include Rift Valley, Western, Nyanza, Eastern, Central and Coast.

2. To create a GIS tool that automates the assessment process and identifies potential locations of biomass plants. This tool was created for analyses in the Rift Valley Province.

1.2 Thesis structure

Chapter 1 provides the reader with general background information on biomass utilisation trends as an energy source. The need for a better understanding of the availability and geographical distribution of biomass resources in ensuring more advanced utilization of the resource is highlighted. The focus of this research is discussed and justified and the overall research aim and objectives are identified.

Chapter 2 reviews the literature on the use of biomass resources with specific emphasis on Kenya and other developing countries. The chapter also highlights the various characteristics of different crop residues. In addition, studies that utilised GIS for biomass assessments and identification of cropland and potential sites of biomass plants are discussed.

Chapter 3 provides a description of the methods used in the study. A detailed outline of the study area, collection of statistical and spatial information on crop production at the district level are included. This chapter also provides information on how GIS was used in the assessment process and the procedure for creating the model tool.

Chapter 4 presents the results of crop residue biomass generated from six provinces in Kenya; Rift Valley, Nyanza, Western, Eastern, Central and Coast and later focuses on Rift Valley for each of the following four crops: maize, wheat, rice and sugarcane. This chapter also presents the energy potential of estimated crop residues. The GIS model tool workflow is presented together with results from the model analysis.

Chapter 5 provides a detailed discussion of the results of crop residues and their energy potential as presented in the previous chapter. The chapter places specific emphasis on the utilisation of GIS as an important tool for residue assessment. In addition, the study provides a conclusion on the future of utilising crop residues for energy generation in Kenya and finally considers future research directions.

Chapter 2 Literature Review

In order to assess the amount and geographical distribution of crop residues in Kenya, it is necessary to review research in the area of crop residue use for energy generation. In addition, a review of literature on studies utilising GIS for crop residue assessments, cropland cover identification and potential power plant locations was also conducted and provides key research findings that were used to guide the methods that were utilised in this study.

2.1 Biomass utilisation in Kenya

Currently, biomass supplies the bulk of the energy requirements for the rural households in Kenya. For instance, biomass supplied about 90% of the rural households' energy requirements in 2008 (Karekezi, Kimani, et al., 2008). However, lack of alternative energy options has led to its extensive utilisation in crude form (Janssen & Rutz, 2012). Sudha and Ravindranath (1999) report that 38% of the total energy needs are being met by biomass in its crude form in developing countries.

Biomass from forestry has been the main source of fuel wood in Kenya. A study by Kituyi et al. (2001) showed that about 15.4 million tonnes of fuel wood were consumed in 1997 and this was supplied by farm land trees, indigenous forests, woodlands and timber off-cuts from plants. Furthermore, this study revealed very minimal utilisation of crop residues as domestic fuel (about 1.4 million tonnes). However, fuel wood supply has been declining in rural Africa (Jama et al., 2008). Various researchers have reported this shortage in Kenya (Kituyi, Marufu, Huber, et al., 2001; Mahiri, 2003; Ngetich et al., 2009). As a result, there is an increase in the utilisation of crop residues by farmers to fulfil their energy requirements. For example, Mugo (1999) reported that a shortage of fuel wood supplies resulted in approximately 40% of the farmers in western Kenya utilising crop residues and cow dung as domestic energy sources. In other parts of western Kenya, rural households have resorted to buying crop residues in order to cater for their fuel needs (Mahiri, 2003).

Various harmful effects are related to the utilisation of biomass resources using traditional techniques. These include deforestation, indoor air pollution and risky practices in gathering firewood (Janssen & Rutz, 2012). Since 2000, about 6 million deaths have been caused by indoor air pollution worldwide (WHO, 2009; WHO & UNDP, 2009). In Sub-Saharan Africa alone, about 400,000 deaths resulted from indoor air pollution in the same year (Bailis et al., 2005).

Replacing traditional forms of biomass energy use with modern ones would have a number of benefits such as a decrease in the emission of greenhouse gases and forest destruction; reduced health hazards; and an increase in available energy (Janssen & Rutz, 2012). In addition, the utilization of biomass for energy production can contribute considerably to job creation, hence improving the rural economies and reducing rural urban migration (Openshaw, 2010; Thornley et al., 2008). For instance, in Brazil, over 700,000 rural jobs have been created in the sugar-alcohol industry (Zylbersztajn, undated). Elsewhere in the USA, America and Duncan (2001) reported that over 66,000 rural jobs have also been created in biomass power generation and an additional 40,000 in biofuels.

2.2 Crop residue utilization

Several authors have reported a global increase in the utilisation of agricultural residues for energy generation in both developed and developing countries and numerous reasons have been suggested for the increase. Goldemberg (1988) believes that these residues are environmentally friendly when utilised in modern ways compared with the current energy sources, whereas Hayes (1998) thinks that these resources are abundant and cheap and their utilisation will result in the economic benefits mentioned above. Cereal crops have been reported as having the potential to generate large amounts of crop residues (Lal, 2004). Examples of these crops are maize, wheat, barley, oats, sorghum, millet, rice, rye and sugarcane. For instance, in Malaysia, rice husk is being utilized for power generation (Kong, 2000). Furthermore, residue generation from maize, wheat, oats, sorghum, rice and sugarcane has been reported in Zimbabwe and in the European Union (EU) (Jingura & Matengaifa, 2008; Scarlat et al., 2010).

Janssen and Rutz (2011) found that utilising agricultural residues in modern ways has the potential to provide clean energy to rural households in Africa. So far, residues from sugarcane (bagasse) have demonstrated their potential for electricity generation in several countries in Africa. Up to 16 nations in sub-Saharan Africa have been mentioned as being able to provide considerable amounts of their power from bagasse-based cogeneration (Karekezi & Kithyoma, 2005). For instance, Karekezi and Kithyoma (2005) reported that 60% of factories generating bagasse in western Kenya are utilising it as a fuel in their boilers so that they can generate steam and electricity. In Tanzania, the potential for cogeneration has been reported to be about 157GWh and only 9% has been developed (Karekezi, Kithyoma, et al., 2008).

Mauritius has been the most successful African nation at utilising this energy source: nearly 30% of the electricity produced from the sugar industry in Mauritius utilises bagasse. Various advantages have been reported to have resulted from the growth of bagasse-based cogeneration in Mauritius: decreased reliance on imported oil; increased local electricity production;, and a more effective energy sector (Karekezi & Kithyoma, 2005). The main reason for an increase in bagasse-based electricity generation is the availability of the cogeneration equipment in modern sugar processing mills (Deepchand, 2001).

Apart from cogeneration in the sugar industry, other biomass technologies have been identified as being capable of converting other crop residues into valuable energy forms in Africa. In Kenya, the following technologies have been reported as being viable: electricity generation through direct combustion or gasification; briquetting; biogas generation; generation of pyrolytic oil for vehicle fuel; and methanol and ethanol conversion for internal combustion engines (Nzila et al., 2010; K. Senelwa & Sims, 1999; Wamukonya & Jenkins, 1995)

In Kenya, crop residues represent one of the significant sources of biomass since the agricultural sector is the backbone of its economy. In 2008, this sector accounted for 27 % of the GDP (IEA, 2010).Various wastes are generated which are left in the field to decompose or are burnt**.** These are mostly found throughout rural areas.

2.3 Potential of crop residues

Globally, various studies have estimated the potential of crop residues for energy generation. Scarlat et al. (2010) presented a detailed assessment of the amount of crop residues available for energy generation from 27 nations in the EU. Crops considered in this study were wheat, rye, barley, oats, maize, rice, rapeseed and sunflower. Results showed that high amounts of crop residues are produced in this region and have an estimated energy generation of about 1530 PJ/year. High residue potential has been achieved from countries with a large agricultural sector and high agricultural production in the EU such as France, Germany, Romania, Spain, Italy, Hungary and Poland.

In Africa, a number of studies have been conducted to determine the potential of crop residues for energy generation. For instance, Cooper and Laing (2007) presented a rough estimate of the theoretical amount of crop residues for countries in the African continent. Coconut, maize, rice and sugarcane crops were chosen for this investigation because they are regarded as the most important crops cultivated in Africa.

Other crop residue assessments have been conducted in Zimbabwe, Nigeria, Sudan and Ghana (Abdallah, 1991; Duku et al., 2011; Jekayinfa & Scholz, 2009; Jingura & Matengaifa, 2008). These studies determined the residue production for each crop type and their respective energy potential. Typical crops selected in these studies were maize, wheat, rice, sugarcane, sorghum, groundnuts, oil palm and millet.

Cooper and Laing's (2007) research provided some detailed information on crop residue production in Kenya. The total amounts of crop residues that can be generated in Kenya were found to be approximately 5,158,119 metric tonnes with an energy potential of about 64,616 TJ. Results for each crop type are as follows: maize generated about 4,441,000 tonnes with a corresponding energy potential of 62,100 TJ; rice produced about 129,000 tonnes and an energy potential of 1800 TJ; and the sugarcane residue amount was approximately 1,247,000 tonnes with an equivalent energy potential of about 8700 TJ. In addition, Senelwa and Hall (1993) cited by Wamukonya and Jenkins (1995) reported that about 11 million tonnes of agricultural residues are generated annually in Kenya. However, details of the type of crops considered have not been mentioned.

Most researchers in Africa have focused on the estimation of only the total amount of crop residues that can be generated and their energy potential. However, the resource is widely distributed and specific information on crop residue location is also necessary for its efficient utilisation. This forms the initial move towards precisely quantifying the bio energy potential production capacity from this resource (Valdez-Vazquez et al., 2010). Now, a more thorough and detailed assessment of the geographical distribution of crop residues is required for the development of local bio energy systems (Gan & Yu, 2008).

2.4 Agricultural residues

Agricultural residues refer to all organic materials that are generated as a result of the harvesting or processing of agricultural crops. Such residues are classified as either field residues or process residues. Field residues such as maize stalks are usually left in the fields at harvesting time, whereas process residues are produced during crop processing, for example sugarcane bagasse.

2.4.1 Characteristics of agricultural residues

There are a number of crop residue characteristics that are important for their utilisation as a fuel. These are moisture content, bulk density, ash contents, lower heating value (LHV), and chemical composition. High moisture content reduces the energy value of a fuel (Mansaray & Ghaly, 1997), so it is therefore very beneficial that the biomass fuel is utilised at a lower moisture content to reduce the energy wasted initially to remove the excess moisture. Moisture content values can be presented as 'wet basis' (as a percentage of total weight) or 'dry basis' (as a percentage relative to the bone dry density of the product). The values presented are on a wet basis. The bulk density is also an important feature as it has an effect on the transportation, assembling and fuel storage (Natarajan et al., 1998). A description of the selected crop residues and their respective characteristics is highlighted.

Maize residues

Maize stalk

Maize stalk is left behind in the field after harvesting and has a low bulk density and high combustion rate. Its bulk density increases transportation and storage costs therefore densification might be required. Various studies have reported different values for its moisture content. Nzila et al. (2010) reported a moisture content of 6.98% while a slightly lower value of 6.40% was presented by other researchers (Ioannidou et al., 2009; Yaning et al., 2012). Elsewhere, a higher moisture content of about 15% was assumed and utilised in various studies (Duku et al., 2011; Eisentraut, 2010; Jekayinfa & Scholz, 2009). Similarly, different heat values are reported in the literature, for instance, Ioannidou (2009) reported a heat value of 18.17 MJ/Kg while a lower heat value of 15 MJ/kg was reported in other studies (Duku et al., 2011; Eisentraut, 2010; Jekayinfa & Scholz, 2009). Based on the above findings, a moisture content of 6.4% with a corresponding heat value of 18.17 MJ/kg was chosen and used in the study. This is because it appeared more accurate and one of the studies was based on actual measurements for a sample obtained in Africa. A moisture content of 6.98% could not be used since its respective heat value was not known. Lastly, a moisture content of 15% was high compared to the other results therefore it was not used.

Maize cob

This residue is slightly denser than the stalks and is obtained after drying and shelling the maize. The cobs are usually left piled up on the farmers' yards (Milan et al., 2011). They have a higher heat value than maize stalks and because of their high density, densification might not be needed.

For this residue, Bhattacharya et al. (1993) reported a moisture content of 7.53% whereas Ioannidou et al. (2009) reported an almost similar value of 7.57%. In addition, a slightly higher moisture content of 8% was utilised in another study (Milbrandt, 2009). As regards the heating value, Ioannidou et al. (2009) reported it to be 18.25 MJ/kg at a 7.57% moisture content, while Bhattacharya et al. (1993) reported a heating value of 16.3MJ/kg at a moisture content of 7.53%. Milbrandt's (2009) research utilised a heating value of 15MJ/kg at a moisture content of 8%. Findings from these researchers seem inconsistent as it would be expected that lower moisture content would result in higher heat values which was not the case (Bhattacharya et al., 1993; Ioannidou et al., 2009).Therefore, a moisture content of 8% with a corresponding heat value of 15MJ/kg was chosen and utilised in the study.

Rice residues

Rice husk is the external covering of the rice grain. On average, about 20-25% of the total weight of rice produced is in the form of husk (Pathak et al., 1986). Husks are generated after processing the crop after which they are gathered in huge amounts in one site at the rice mills. This reduces transportation and handling costs. Furthermore, husks have a uniform nature which makes them ideal to be utilised in more effective biomass conversion technologies, such as gasification, which requires such qualities for great outcomes.

As with the maize residue, different moisture contents and heating values have been reported for the residue. Channiwala and Parikh (2002) presented a moisture content of 8.47% whereas Perera et al. (2005) utilised a slightly higher moisture content of 9%. In addition, a moisture content of 12.37% was utilised in Milbrandt's (2009) study.

Similarly, Channiwala and Parikh (2002) reported a heating value of 14.693 MJ/kg at an 8.47% moisture content, but Perera et al. (2005) used a slightly lower value of 14 MJ/kg at 9%. In a different study, a heating value of 15.50 MJ/kg was reported, but the corresponding moisture content was not provided (Pathak et al., 1986). Besides, Milbrandt's (2009) research utilised a heating value of 19 MJ/kg at a 12.37% moisture content. Milbrandt's (2009) study was found to be inconsistent in that it had utilised higher heat values at higher moisture content than other studies (Channiwala & Parikh, 2002; Perera et al., 2005). Values from Milbrandt's (2009) research were therefore not considered further. However, results showed that the moisture content of this residue is about 8.5% to 9%. Therefore, a moisture content of 8.47% with a corresponding heating value of 14.67 MJ/kg was chosen and used in the study because lower moisture contents are preferred over higher ones in energy generation.

Rice straw

Straw is normally left in the field after harvesting the rice crop. It has a low bulk density and high combustion rate, thus it is in a low category of use as an energy source. However, densification is normally done to increase its energy potential. Currently, it is utilised as a source of energy by rural households.

A number of researchers have presented several straw moisture contents. Yaning et al. (2012) reported a value of 6.58%, whereas Deng et al. (2009) reported a slightly lower moisture content of 5.12%. In addition, slightly higher values of 8.10% and 12.7% have been reported by other researchers (Channiwala & Parikh, 2002; Perera et al., 2005). Elsewhere, a moisture content of 15% was utilised in various studies (Duku et al., 2011; Eisentraut, 2010; Jekayinfa & Scholz, 2009)

Likewise, different heat values have been reported. Channiwala and Parikh (2002) reported a heating value of 14.85 MJ/kg at an 8.10% moisture content, while Deng et al., (2009) gave a heat value of 17.12 MJ/kg at 5.12%. Other studies (Duku et al., 2011; Eisentraut, 2010; Jekayinfa & Scholz, 2009) utilised a heating value of 15.56 MJ/kg corresponding to 15% moisture content. Lastly, a heating value of 16 MJ/kg corresponding to a moisture content of 12.7% was utilised in Perera et al.'s (2005) study. Based on the above findings the moisture content of 15% was ignored since it was not based on actual measurements. A moisture content of 6.58% was also not considered since its heat value was not reported. In addition, a moisture content of 5.12% was significantly lower hence it was not selected. A moisture content of 8.10% was expected to yield higher heat values than a moisture content of 12.7% but surprisingly was not the case. Based on the above findings, a moisture content of 8.10% with a corresponding heat value of 14.85MJ/kg was chosen since it was low and therefore preferred over a high moisture content of 12.7%. In addition, it was also based on actual measurements in an Asian country whose conditions are more or less similar to those of Africa.

Wheat residues

Wheat straw

Straw is left behind in the field as residue after harvesting. It also has a low bulk density and a high combustion rate, therefore it, might require densification. Similarly to the above mentioned residues, different values have been reported for its moisture content and heating values. Adapa et al. (2010) reported a moisture content of between 4.3 – 9.5%, while Yaning et al. (2012) reported a value of 7.79%. In addition, a moisture content of 7.3% was presented in another study (Demirbas, 2004), whereas Channiwala and Parikh (2002) reported a moisture content of 8.87%. However, a higher moisture content of 15% was utilised in a different study (Eisentraut, 2010). All the other studies have reported a moisture content that is in agreement with findings by Adapa et al. (2010) except for the moisture content utilised in Eisentraut's (2010) study which is significantly different.

Most of the heating values reported for this residue did not have corresponding moisture contents. For instance, Munir et al. (2009) reported a heating value of 17.98 MJ/Kg while Pathak et al. (1986) presented one of 17.20 MJ/kg. Both studies did not present the corresponding moisture content and only Channiwala and Parikh (2002) reported a heating value of 17.98 MJ/kg which was attained at a moisture content of 8.87%. Since this moisture content is in the same range as other findings, it was selected together with its corresponding heat value to be utilised in the study.

Sugarcane residues

Bagasse

Bagasse is a fibrous hard product that is generated as a by-product of sugarcane processing. The residue is usually collected in huge quantities at one site thus making it simple to manage and transport. There are also variations in its characteristics as with other crop residues. A moisture content of 50% was presented by various researchers (Channiwala & Parikh, 2002; Koopmans & Koppejan, 1997; Perera et al., 2005), while a slightly lower moisture content of 46% was reported in another study (Chen et al., 2012). For the heating value, 8.6 MJ/kg achieved at 50% moisture content was reported by Perera et al. (2005) while Drummond and Drummond (1996) reported a lower heating value of 5.4%. In addition Koopmans and Koppejan (1997) reported a heating value of 7.75 MJ/kg. Based on these findings, a moisture content of 50% was utilised in the study. Because slightly different heating values were reported at 50% moisture content, a higher value of 8.6MJ/kg was selected.

Tops and Leaves

Tops and leaves are left in the field as residues after harvesting sugarcane stems due to their low sugar content and studies have reported different values of moisture content and heating value for this residue. Nzila et al. (2010) reported a moisture content of 6.49% while Yaning et al. (2012) presented a slightly higher value of 8.15%. A heating value of 15.8 MJ/kg at 11%

moisture content has been reported in the literature (Perera et al., 2005). In addition, other researchers have reported a heating value of 15.81MJ/kg - 17.41MJ/kg (Koopmans & Koppejan, 1997). For this study, a moisture content of 6.49% was selected because this was based on actual measurements in Kenya. Furthermore, a heating value of 15.8 MJ/kg was chosen because it has been reported in more studies.

Other important characteristics of these residues are displayed in Table 1

Table 1 Characteristics of crop residues

			Chemical composition			
Type of crop residue	**Bulk density (Kg/m^3)**	**Ash content**	**C**	**H**	**O**	**N**
Maize cobs		13.8[c]				
Maize stalks	127.32[a]	5.7[c]	47.1			0.8
Wheat straw	160.75[a]	6.9[b]	43.0	5.4	47.0	0.1
Rice husk	86 - 114[d]	21.24[b]	38.5	5.2	34.6	0.5
Rice straw	166.29[a]	20.38[b]	35.7	4.6	39.1	0.3
Sugarcane bagasse		3.2[b]	45.5	6.0	45.2	0.2
Sugarcane tops and leaves	110.86[a]	1.2[c]				

Sources:

a) Yaning et al. (2012)

b) Channiwala and Parikh (2002)

c) Koopmans and Koppejan (1997)

d) Perera et al. (2005)

All the values on the chemical composition have been reported by Channiwala and Parikh (2002).

2.5 GIS in biomass assessment

The spatial distribution of the biomass resource has raised the interest of researchers in utilising GIS for its assessment. GIS is a computer-based tool designed for capturing, storing, verifying, incorporating, manipulating, scrutinizing and displaying information associated with locations on the earth's surface. It facilitates exploration of spatial data and successfully creates multiple layers of information (Dagnall & Pegg, 2000). The main characteristic of GIS is its ability to locate information geographically. By utilizing GIS, the availability and spatial distribution of biomass resources are identified which is essential for their successful exploitation. This is very important as it provides information on the best sites for locating bioenergy plants

(Chanthunyagarn et al., 2004; Voivontas et al., 2001). In addition, the variables for measuring biomass can be adjusted in future to determine the status of the biomass resource at that time (Fernandes & Costa, 2010). Furthermore, it enables findings to be displayed on maps making them easier to interpret than traditional reporting. Lastly, GIS can be used to create model tools that automate processes. This enables GIS processes to be rerun in future and no codes are required.

So far, GIS has been utilised in various studies to estimate the potential of crop residues for energy generation. One of the first applications of GIS in biomass assessment presented a Decision Support System (DSS) that provided an approach that can be used to estimate the potential of agricultural residues for power generation and identify their geographical distribution (Voivontas et al., 2001). This method launched four levels in the assessment of residues which are: theoretical, available, technological and economically usable residues. These researchers define the theoretical amount of crop residues as the total sum of all agricultural residues produced in a given region per year. This is the maximum amount of residues that can be generated in a given area for bio energy. They also stated that the theoretical biomass potential from agricultural residues for any particular region is a function of the area planted and the crop yields for each crop. Biomass estimation using DSS entails the creation of a GIS database of cultivated crops to be used for the estimation and presentation of the biomass potential in any geographic analysis.

This approach was applied in Creta, a region in Greece, to emphasise its role with the aim of estimating the biomass potential (Voivontas et al., 2001). The following datasets were utilised: digital maps' administrative boundaries; location of towns and other demographic data; spatial data on cultivated crop areas; statistical data for cultivated areas and types of cultivation; and characteristics of the residues. Results showed high biomass potential from this region. In addition, the geographical distribution of the biomass residues was presented in a map.

Globally, various studies have also utilised GIS to estimate the theoretical amount of agricultural residues and their energy potential (Ćosić et al., 2011; Fernandes & Costa, 2010; Hiloidhari & Baruah, 2011; Jiang et al., 2012; Milbrandt, 2009; Singh et al., 2008, 2011; Vasco & Costa, 2009). These studies have utilised Voivontas et al.'s (2001) approach to estimate the theoretical amount of crop residues. The results presented comprised the amount of agricultural residues that can be generated and their energy potential and their spatial distribution. One of the characteristics of the GIS software is its ability to automate processes which has not been considered in most of these studies.

So far, a few studies have been conducted to establish the spatial distribution of biomass resources in Africa. Vasco and Costa (2009) utilised GIS to estimate the amount of forest residues generated in Maputo province, Mozambique and concluded that about 1,233,412 tonnes/year of forest residues with an equivalent energy potential of 17,267,771 GJ/year are generated in this region. In addition, the authors were able to present the spatial distribution of the available biomass resources in a map. These results are great because the areas with high residue production can be easily identified on a map.

In Liberia, Milbrandt (2009) used GIS to quantify the theoretical amount of crop residues that can be produced from each county. He utilised Voivontas's (2001) approach to analyse and come up with conclusions. It was found that about 125,000 tonnes of food crop residues can be generated annually in this nation and these results were presented on a map. However, owing to lack of crop production statistics for some crops at county level, an assumption was made to estimate them which was that, in any one county, the yields of a particular crop and resultant residues are the same for all families planting that crop. Hence, information on the number of farming families in a county and the percentage of those planting a specific crop was obtained. Crop yields at county level were then estimated.

In most of the studies (GIS based and non-GIS based), the potential of crop residues for energy generation has been assessed based on cultivated crop, crop yield, residues yield, crop area and residue coefficients (i.e. straw to grain ratio (Jingura & Matengaifa, 2008; Nzila et al., 2010; Scarlat et al., 2010; Singh et al., 2008). This was estimated both at local (Beccali et al., 2009; Fernandes & Costa, 2010; Vasco & Costa, 2009) and national levels (Karaj et al., 2010; Lewandowski et al., 2006) and to some extent globally (Scarlat et al., 2010).

Lack of information on the geographical distribution of biomass resources in SSA has been mentioned as one of the key barriers to the introduction of one of the modern biomass conversion technologies in sub Saharan Africa (Dasappa, 2011). It is evident that more research needs to be conducted in the African continent to determine the potential of crop residues for energy generated especially the geographical distribution. This will assist with the introduction of the already identified biomass conversion technologies and provision of cleaner energy to the rural households.

2.6 Potential sites for biomass power plants

The spatial distribution of the biomass resource and the collection distance are key factors affecting the selection of potential sites of the biomass plants (Voivontas et al., 2001). This ensures that there is sufficient feedstock for the plant and the transport costs are minimised. The DSS earlier mentioned can also be used to determine biomass plant locations. In this approach, site selection begins with the identification of candidate sites which are assigned to the centroids of region objects. An acceptable biomass collection distance is then determined which is used to specify the collection area for each site. Potential locations of power plants are then established, which in this case were located closer to the road network.

Potential power plants have been located nearer to the road network in other studies. Shi et al., (2008) assigned candidate plants along the roads while choosing optimal sites for biomass power plants in Guangdong province.

In Africa, GIS has been utilised to locate possible locations of biomass power plants in Maputo province, Mozambique (Vasco & Costa, 2009). In this study, forestry residues were the feedstock considered and potential sites were in areas with high production of the forestry residues and in locations with good transport networks. In a non-GIS based study conducted in Kenya, potential sites for a biomass gasifier were identified based on the amount of biomass generated and the proximity of the biomass resource to the rural households (K. Senelwa & Sims, 1999).

No information was found regarding anyone identifying a potential site for a power plant in Africa using GIS by utilising biomass from agriculture.

2.7 Identification of cropland cover

An approach for creating a cropland map for sub-Saharan Africa has been presented by Fritz et al. (2011). In this study, five different land cover datasets were utilised which are GLC-2000, MODIS Land cover, GlobCover, MODIS Crop Likelihood and Africover. The Africover land use dataset was given the highest priority in this analysis because it is specifically created for the African continent. However, various adjustments were made on the cropland map using crop production statistics, especially when there were very significant variations in the findings. Results indicated the highest accuracies in Eastern Africa, which was attributed to the inclusion of the Africover land use dataset, but very low accuracies in Western Africa. Owing to the availability of experts trained in the recognition of cropland areas, the created cropland map was validated using Google Earth. It can be surmised that in-adequate research has been conducted in the identification of the cropland cover in Africa.

Chapter 3 Research Methods

This study aims to estimate the spatial potential of crop residues in Kenya and present a tool that automates the assessment process. In addition, it identifies potential sites for biomass energy plants. It was conducted for Kenya, located in East Africa, and six provinces were selected with a more detailed analysis focusing on Rift Valley Province. It was a quantitative study and entailed the collection of statistical data from the Ministry of Agriculture, spatial data from the World Agroforestry Centre, both situated in Nairobi, Kenya, and other information from literature. Required datasets were prepared in Excel and analysed using ArcGIS software. ArcGIS extension Model Builder was used to create a tool that automates the crop residue biomass assessment process and to identify potential sites for biomass plants in Rift Valley Province.

3.1 Study Area

3.1.1 An overview of Kenya

Kenya is located on the East African coast, on latitude 1° 00' north of the Equator and longitude 38° 00' east of the Greenwich meridian. Its neighbouring countries include Ethiopia, Sudan, Somalia, Uganda and Tanzania. It covers a total area of approximately 580,370km^2 (Aquastat, 2009). Its administrative boundaries comprise eight provinces and 69 districts which are further subdivided into smaller administrative units. These provinces are Nairobi, Rift Valley, Western, Coast, Nyanza, Eastern, Central and North Eastern. However, in August 2010, a new constitution was promulgated which assigns 47 counties as the main administrative units in the future. Kenya has a population of about 43 million people (CIA, 2008) and Nairobi, Kenya’s capital city is a component of the Kenyan highlands which consists of the majority of prospering agricultural production regions in Africa (CIA, 2008, p. 2). Kenya’s economy relies on natural resources and agriculture which employ over 80% of the population.

The study was conducted in six provinces; Rift Valley, Western, Nyanza, Central, Coast and Eastern. These provinces were chosen due to the high economic and environmental value of their agricultural activities. A more detailed assessment was conducted for Rift Valley Province because it presents the highest agricultural activities, occupies the largest area and has the largest population in the nation.

A map showing the geographical location of Kenya in Africa and of Rift Valley Province in Kenya, as well the geographical distribution of the districts in Rift Valley Province is shown in Figure 1.

Figure 1 Map showing the location of Kenya in Africa, as well as Rift Valley Province in Kenya, in addition to the geographical distribution of the districts in the province

3.2 Materials

3.2.1 Selection of agricultural crops

Four crops namely maize, wheat, rice and sugarcane were chosen for the study. The main reason for their selection was because these cereal crops have been reported as having a high potential for generating residues (Lal, 2004). In addition maize, wheat and rice are very important agricultural crops in Kenya, being widely grown, while sugarcane residues have indicated a high potential for energy generation ("Cereals: Kenya," 2011; Osawa, 2004).

Agricultural residues

This study considers both field and process residues for selected crop types to ensure an accurate assessment of their total potential in Kenya. Residues selected in the study are maize stalks, maize cobs, rice straw, rice husk, sugarcane bagasse, sugarcane tops and leaves and wheat straw. As opposed to direct computation, crop residue assessments are expressed based on information on the area, crop yields and residue to product ratios.

3.2.2 Data

The study utilised both spatial (GIS layers) and non-spatial data. The spatial data used to accomplish this research was obtained from the World Agroforestry Centre (ICRAF) GIS research laboratory, located in Nairobi, Kenya. ICRAF was chosen because its data was freely available and accessible. This data is as follows:

- The population shape file which has spatial information on the administrative boundaries for Kenya. This data was primarily collected during the 1999 population census. This shape file was used to extract the administrative boundaries of the study area.
- The land cover shape file which was originally produced by Africover and last updated in 2002. Africover is a project initiated by the United Nations (UN) and its objective is to gather and assemble all geographical information on land cover, climate conditions and natural resources in Africa using remote sensing. This shape file comprises of a “legend” file which represents the thematic content and lists all the land cover types that have been identified and mapped in a specific country. This file contains information on the user label classes (also referred to as LCC own labels) and their descriptions and was

used to extract the herbaceous crops grown in Kenya that were being considered in the study.

- The road shape file which has spatial information on the road types in Kenya. Roads with a gravel surface were extracted from this shape file and used in the identification of potential sites for biomass energy plants in the selected province.

The non-spatial data used in the research included secondary data in form of annual crop reports which were obtained from the Ministry of Agriculture in Kenya (MoA, 2010). MoA is responsible for collecting crop production statistics for each planting season. Data from 2008 to 2010 was used in the study, except for western province where only two year data was used, owing to the unavailability of 2008 data.

These reports contained information on the type of crops, crop yields, yields per hectare and area cultivated for each district in the province. Production for maize, wheat and rice was reported as bags per unit of crop area while sugarcane yields were reported in tonnes. A bag commonly recognised as a gunny bag is described as a sack manufactured from gunny or burlap and it is used for storage or carrying commodities, for example grains (Wambugu et al., 2009) . In developing countries, gunny bags have been recommended for storing grain crops (Gahukar, 1994) and in Kenya, for instance, they are used for storing food grain crops and other agricultural products (Abdi, 2004). These bags are also used for marketing the grain crops and different grain crops are stored at different weights in the gunny bags in Kenya. The weight for maize and wheat in a gunny bag is 90kg while rice is 50kg (Kiome, 2009). Secondary data was ideal in the study because it was convenient, readily available and large amounts of data could be collected in a short period of time.

Additional information required in the study included

- Residue-to-product ratio (RPR) which shows the amount of residue that can be obtained for each tonne of produce. Given that there was limited information on specific RPR for crops in Kenya, average or widely reported values in African studies were utilised (Cooper & Laing, 2007; Eisentraut, 2010; Jekayinfa & Scholz, 2009). However, these values were based on actual measurements in Asian countries (Koopmans & Koppejan, 1997). Since this ratio varies for different crops and crop varieties grown, it was assumed that these might be similar for African nations owing to the climatic conditions experienced. RPR used in this study are displayed in Table 2.

- The percentage of dry matter for the crop residues was estimated from their % moisture content using the following equation:

  % Dry Matter = 100 - % Moisture

- To estimate the energy content of the crop residues, the lower heating value (LHV) was utilised. Information on the LVH was acquired from literature (see Section 2.4.1) and can also be found in Table 2.

Table 2 Residue to product ratio, % dry matter and lower heating value for the crop residue types

Type of crop residue	**Residue to product ratio (RPR)**	**% Dry matter**	**Lower heating value (MJ/Kg)**
Maize cobs	0.27	92	15
Maize stalks	1.5	93.6	18.17
Wheat straw	1.2	91.1	17.98
Rice husk	0.27	91.5	14.67
Rice straw	1.5	91.9	14.85
Sugarcane bagasse	0.3	50	8.6
Sugarcane tops and leaves	0.3	93.5	15.8

Where MJ = Mega Joules

3.3.3 Software and Functions

The tools and software utilised in this study for analysis and reporting are listed in Table 3.

Table 3 Software utilised for this research and their use (s)

Software	**Use**
ArcGIS 10	Projection allocations
	Geometry modifications and calculations
	Clipping layers
	Extracting layers
	Preparing maps
	Creating the GIS Residue analysis tool
Microsoft Excel	Spreadsheet preparations
	Preparing graphs and tables
Microsoft Word	Thesis writing

3.3 Approach

The research was grouped into three main steps to attain its objectives. The first was the estimation of crop residue biomass with three sub-stages, including identification of the spatial area under cropland in Kenya, estimation of yields for each crop per polygon in each district and the assessment of crop residue biomass. In step two, the energy potential of the crop residues was calculated. After that, a GIS tool which automates the crop biomass assessment process and identifies potential sites for biomass plants was created. The steps followed are as displayed in Figure 2.

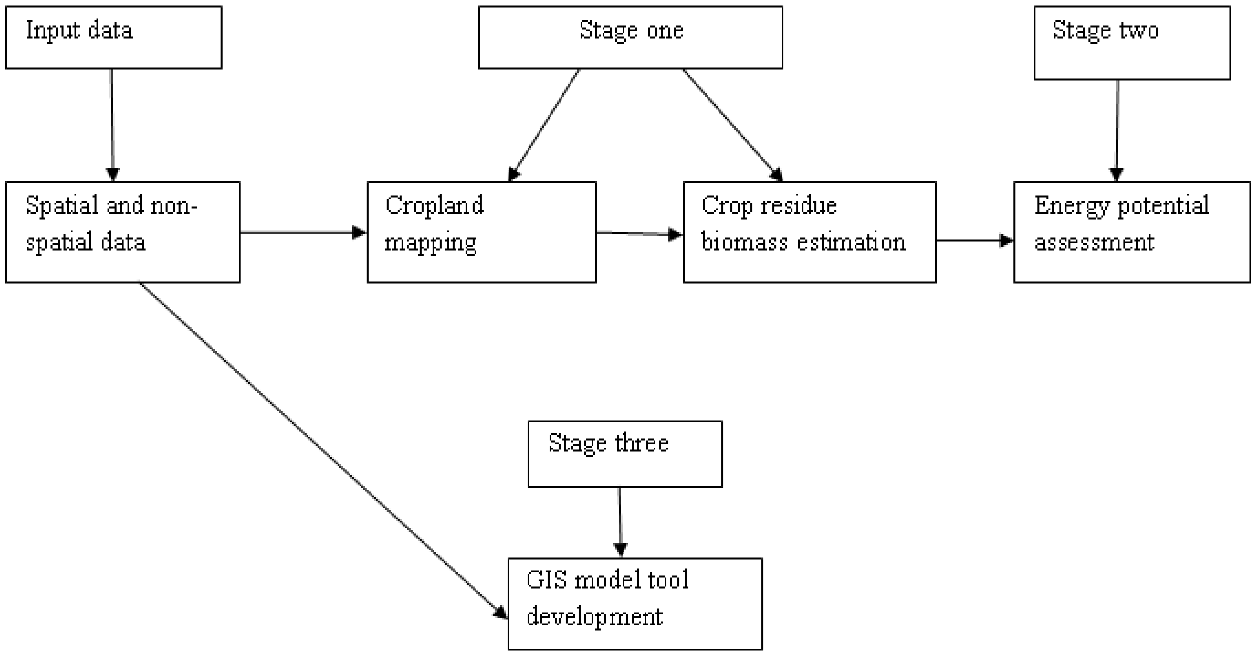

Figure 2 Overview for each of the stages in this research

3.3.1 Estimating crop residue biomass

In this section, the approach utilised in estimating the theoretical amount of crop residues produced in Kenya is presented. The theoretical amount is described as the total sum of all agricultural residues produced in a given region per year (Voivontas et al., 2001). This is the maximum amount of agricultural residues that can be produced in a given area for energy generation. The spatial location of the crops was established before estimating the biomass residues that can be generated.

Identification of cropland

The spatial data obtained from ICRAF were in decimal degrees; therefore, a suitable projection had to be determined for this task. For practical purposes, Africa Lambert Conformal Conic was preferred because this was specifically assigned to the African continent and there was none nominated for Kenya. District administrative boundaries were then extracted from the population shape file and they formed the boundaries of the study area. The result was a polygon of 69 districts for the whole country. The land cover shape file was then overlaid onto the created "district boundaries" layer. Owing to its variation in size, it was clipped to the size of the newly created layer. After that, the union overlay tool was utilised to identify the land use types for each district.

Thematic aggregation of the land cover data which is a method whereby the user modifies the land cover of a country to get information of one land cover type the user requires was then performed. This aggregation was carried out to extract the location of crops considered in this study. The "legend" file was the main source of information in this exercise. In addition information from the land cover classifier list, Land Cover Classification System (LCCS) and table of aggregation for Kenya were also used which are located in Appendix 1A and 1B.

In this stage, an Excel spreadsheet was first prepared to assign the different user labels to the four crops. User labels that had a crop sub class as a suffix as indicated in the table of aggregation were assigned to that crop. However, user labels without a suffix and those that had two crop sub classes as suffixes resulted in various assumptions being made. For example, user labels HD4 and HM4 had suffixes for wheat and maize. In this case, a summary statistics was conducted to determine which crop had the highest count. It was found that wheat had a higher count for HD4 than maize, and maize had a higher count for HM4 than wheat as indicated in Table 4. Therefore HD4 was assumed to be wheat while HM4 was assumed to be maize. In addition, it was assumed that user labels that had a particular crop sub class as a suffix, and in another instance did not, should be allocated to that crop.

There were also some polygons that consisted of two or three land cover classes. This meant that the crops did not cover the entire area of these polygons. With the help of the user label codes, the percentage coverage was also assigned. This was to assist in the calculation of the "corrected area" for each polygon. Appendix 1A shows how the different user labels were assigned to the four crops and their percentage coverage. This Excel table was then joined to the district land use layer and the spatial distribution of the four crops was identified. As a result, a new shape file was created. The correct area was then computed in hectares for each polygon.

Although this aggregation led to the identification of the crop land for the four crops in Kenya, it also could potentially incur inaccuracies because of the various assumptions that were undertaken. Validation of the cropland map was not conducted as it was outside of the scope of this project.

Table 4 Number of counts from user labels HD4 and HM4

User label	Counts
HD4-MZ	3
HD4-W	33
HM4-MZ	43
HM4-W	3

Crop biomass estimation

Once the mapping of the crops was completed, the amount of crop residue biomass that could be obtained spatially was calculated. Since the spatial data had different polygons for each district, this stage commenced with the organisation of crop production data using Excel software. An Excel table of average annual crop yields (in tonnes) per hectare for each district was therefore prepared. A three year average was used to cater for fluctuations in production in different years as stated by (Rosillo-Calle & Woods, 2012). The area cultivated was assumed to be that mapped under cropland after the aggregation.

The GIS model was first explored to determine the yields for each crop per polygon. Once the crop yields of any particular crop are known, the resultant residues can be estimated using residue to product ratio. Therefore, residues generated from each crop were estimated using Equation 1.

Crop residue (BDT) = crop production * crop to residue ratio * % Dry Matter   Equation 1

Where BDT= is bone dry tonnes

3.3.2 Estimation of crop residue energy potential

Assessment of the energy potential is normally accomplished using annual crop residues generated for each crop. The energy potential of the residues was assessed using Equation 2 as follows:

Heat value = Amount of biomass per polygon in tonnes × LHV Equation 2

Energy potential was expressed in Terra Joules (TJ)

3.3.3 GIS Model tool development

This section presents the process used in the development of a GIS Model tool. The tool automates the process of estimating the theoretical amount of crop residues and their energy potential and also establishes their geographical distribution. In addition, it also identifies potential sites for biomass power plants. This tool was created for Rift Valley Province and is transferable to every other region so that the local energy planners can supply the model with their own parameters to obtain locally based results.

Study area

The study area for developing the GIS-tool was Rift Valley Province which is located on latitude 0^o 30’0” N and longitude 36^o 0’ 0”E. This province is the largest and most highly populated and one of the most economically significant amongst the eight provinces of the Republic of Kenya. It occupies an area of about 182 413 square kilometres according to the 1999 population census and has a population of approximately nine million people. The administration of this province is subdivided into 18 districts as shown in Figure 1, which are further subdivided into smaller administrative units. The smallest administrative unit in this analysis was a district.

GIS Residue Analysis Tool

This tool was built with ArcGIS Model Builder and its objectives were to automate the process of estimating the theoretical amount of crop residue biomass and its energy potential, present the spatial distribution of the residues and identify potential sites for biomass power plants. The input datasets to this tool included the “projected” population, land use and roads shape files and two Excel spreadsheets. The first spreadsheet contained information to aid in thematic aggregation (Appendix 1A) while the second table comprised crop production data organised for each crop per hectare for each district (Appendix 2).

This model was created following the steps in 3.3.1 and 3.3.2 together with the accompanying assumptions. In addition, potential sites of biomass plants were identified using the procedure outlined below. While creating this model, some model inputs were set as parameters to enable the user to change them based on their region and information required. These included population and land use features, a spreadsheet on crop yields, possible plants and buffer distance. There were also model preconditions which controlled the flow of some processes and ensure that they ran systematically. This model presents the results of the residues in Rift Valley Province and can be viewed in Figure 3.

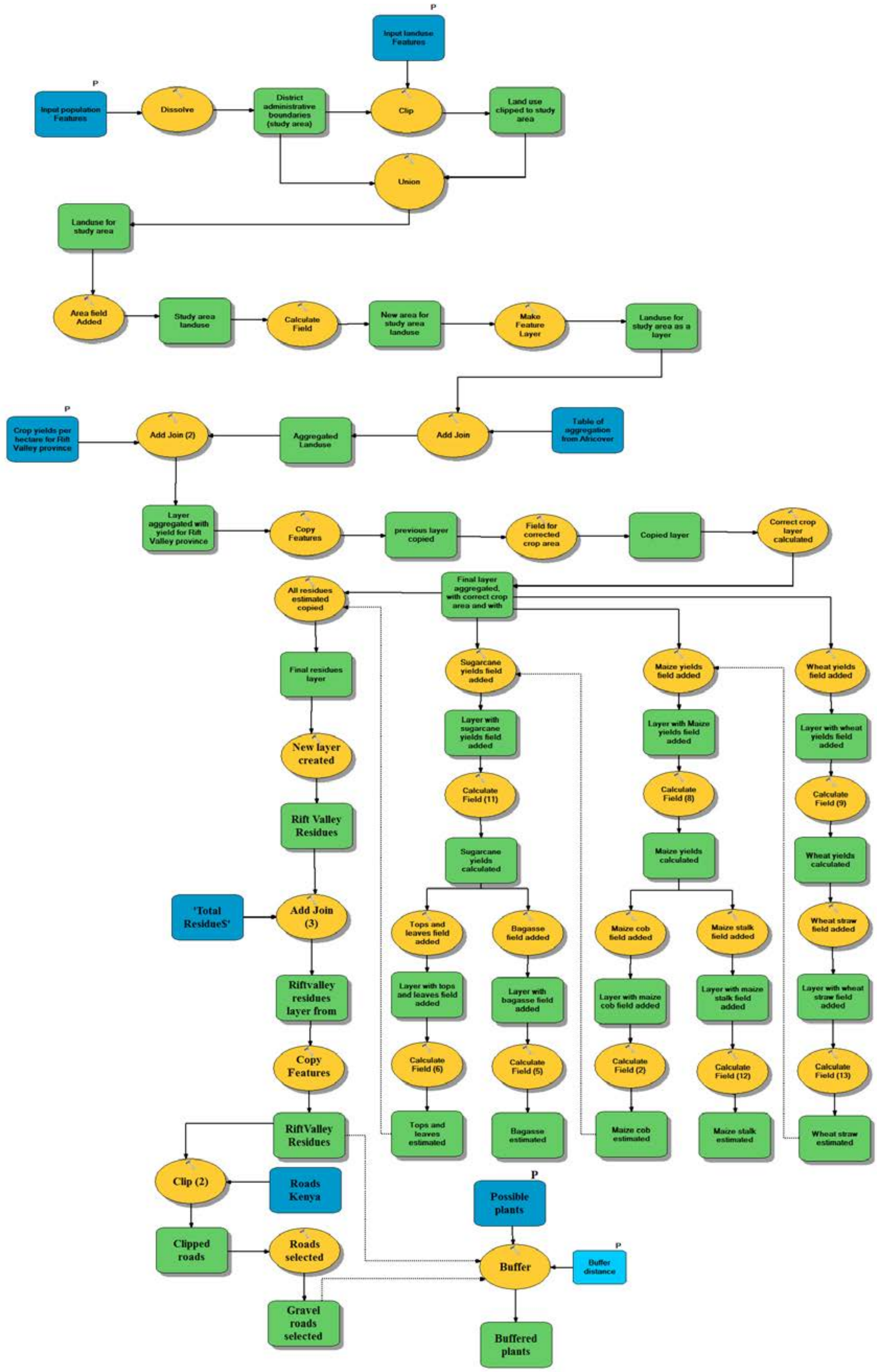

Figure 3 Model tool workflow for crop residue assessment and identifying potential sites for biomass plants

Procedure for identifying potential sites of biomass plants

In identifying potential sites for biomass power plants, sites that are closer to roads and with high residue catchment are preferred. Bates et al. (1996) stated that building power plants nearer to residue catchments reduces obstruction on roads and decreases transport costs. In this study, possible biomass power plants were sited closer to, or on the road network, and in areas where a high amount of residue could be collected at a radius of between 10 – 20km. For comparison purposes, biomass plants were also sited in areas with little residue concentrations. The road shape file for Kenya had roads with various surface types which included gravel, earth, GAP and surface dressing. In this study, gravel roads that are in either a fair or good condition were selected. This is because along these roads there is accessibility to other resources which are important to a biomass plant such as an electricity network and water connection. Earth roads were not considered as they connect to villages and not many other important networks. In the model, possible plants were set as a parameter and the model dialog box allows the user to select a potential site interactively in ArcMap. Buffer radii of 10 – 30km were applied to a selected number of potential sites and the amount of crop residue that can be collected was estimated. This radius has been suggested as the best distance to minimise costs and traffic difficulties (Panoutsou, 1998).

Chapter 4 Results

This chapter reveals the results of the analysis described in Chapter Three, Research Methods. The results are initially presented for all the six provinces in Kenya: Rift Valley, Nyanza, Western, Eastern, Central and Coast and later focus on Rift Valley.

4.1 Estimating crop residue biomass

This section presents results of the crop residue biomass generated from all the six provinces. Biomass supply was assessed for each of the four crops: maize, wheat, rice and sugarcane.

4.1.1 Geographical location of crops

To facilitate the estimation of the spatial potential of crop residues and their respective energy, the geographical location of the crops was identified and presented on a map. Figure 4 presents a map of the planted crop area in Kenya obtained as a result of the thematic aggregation of the land use data. It shows crop production as being located mostly on the western and south central regions. The total area mapped for the four crops was found to be about 3,234,300 hectares (Table 5). Amongst the provinces, Eastern contributed the most to the total area with about 34%, followed by Rift Valley with 32% and then Nyanza with 11%. Coast province had the least amount of coverage with only 6%. Of the four crops, maize was found to be the most cultivated crop in the country. It contributed about 86% of the total planted area followed by wheat at 11%. Sugarcane and rice had the least coverage contributing about 1%. The results also indicated very minimal crop production in the Eastern and Northern regions of the country.

However, according to FAO (2012), the total area harvested for the four crops was about 2.0 million hectares in 2008, considerably less than the resulting GIS estimate. A comparison of the area under maize production was then carried out to evaluate the accuracy of the created cropland map. Maize was chosen because it is the main food crop grown in Kenya. In 2008, Rift Valley Province had the highest maize production area of about 550,000 ha. In this study, Eastern Province was found to have the highest area under maize of about 1.0 million hectares (Table 5), but this Province only had an area of about 500,000 hectares in 2008 (FAO, 2012). Owing to unavailability of further data to correct for these differences, this cropland map had to be used even though it is likely to have some mistakes.

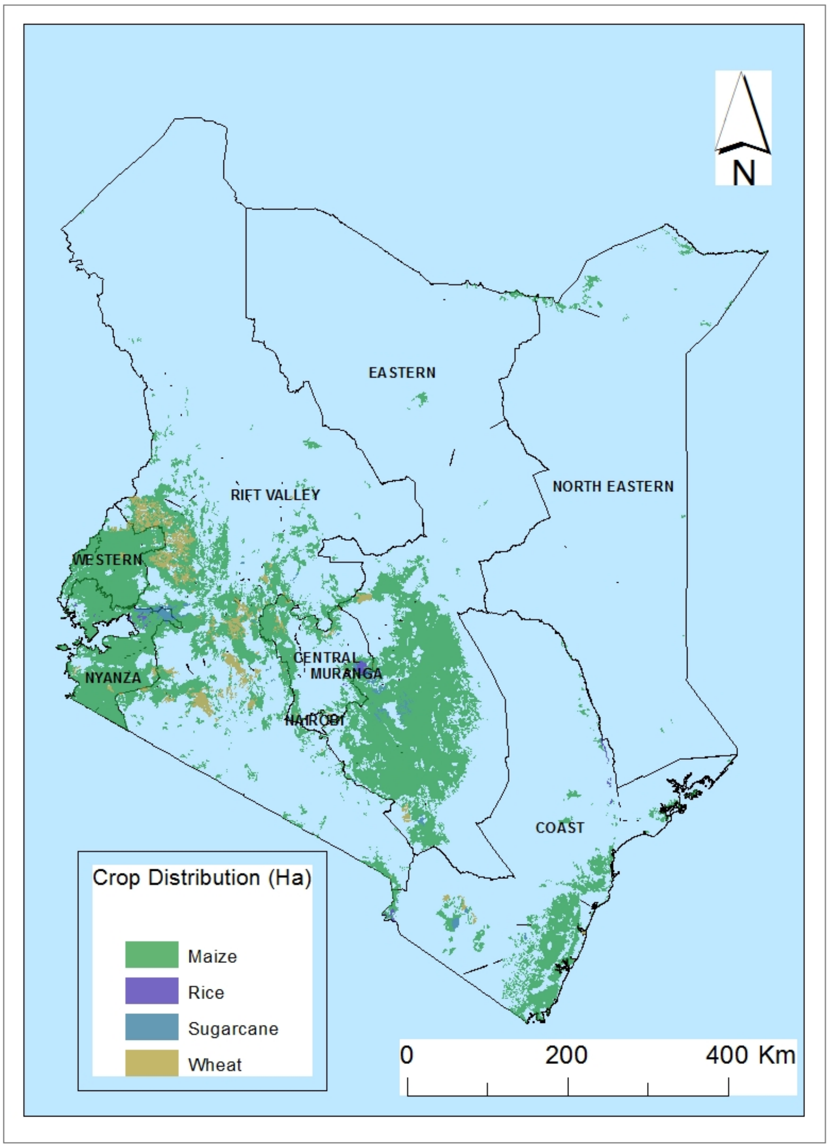

Figure 4 Spatial locations of maize, rice, and sugarcane and wheat crops in Kenya

Table 5 Area harvested, average crop production and average yields for the four crops in six provinces

	Rift Valley Province	**Nyanza Province**	**Western Province**	**Eastern Province**	**Central Province**	**Coast Province**
Maize						
Area harvested (ha)	699,900	337,400	317,900	1,073,900	168,500	187,100
Average crop production (tonnes)	1,755,800	549,800	453,000	400,000	165,900	118,500
Average yields (tonnes/ha)	2.50	1.60	1.40	0.37	0.98	0.63
Wheat						
Area harvested (ha)	311,600	-	11,000	22,600	16,000	-
Average crop production (tonnes)	300,900	-	220	63,700	16,500	-
Average yields (tonnes/ha)	0.97	-	0.02	2.80	1.03	-
Rice						
Area harvested (ha)	-	7,000	-	-	15,300	8,200
Average crop production (tonnes)	-	12,700	-	-	20,200	900
Average yields (tonnes/ha)	-	1.80	-	-	1.32	0.11
Sugarcane						
Area harvested (ha)	25,100	32,800	-	-	-	-
Average crop production (tonnes)	1,733,600	2,516,700	-	-	-	-
Average yields (tonnes/ha)	68.97	76.80	-	-	-	-

4.1.2 Residue production from regions

The total amount of crop residue biomass estimated in Kenya was about 7,384,600 tonnes. This is sub-divided for each of the provinces and districts (Figure 5 and Appendix 3). Rift Valley Province had the highest residue production of 3,866,000 tonnes followed by Nyanza with around 1,493,300 tonnes whereas Coast Province had the least production of approximately 203,100 tonnes.

At district level, the residue production varied between 744,740 tonnes and 560 tonnes. Most of the biomass was generated from Nandi, Uasin Gishu, Nyando and Trans Nzoia districts with a residue production of 744,740, 605,810, 592,800 and 576,600 tonnes respectively (Table 8 and Appendix 3). These districts are located in Rift Valley Province except for Nyando which is in Nyanza Province. The lowest residue was generated from Isiolo district in Eastern Province. This difference in residue production is because of variations in crop yields per hectare and the difference in the type of crop residues in each of the regions (Tables 5 and 6).

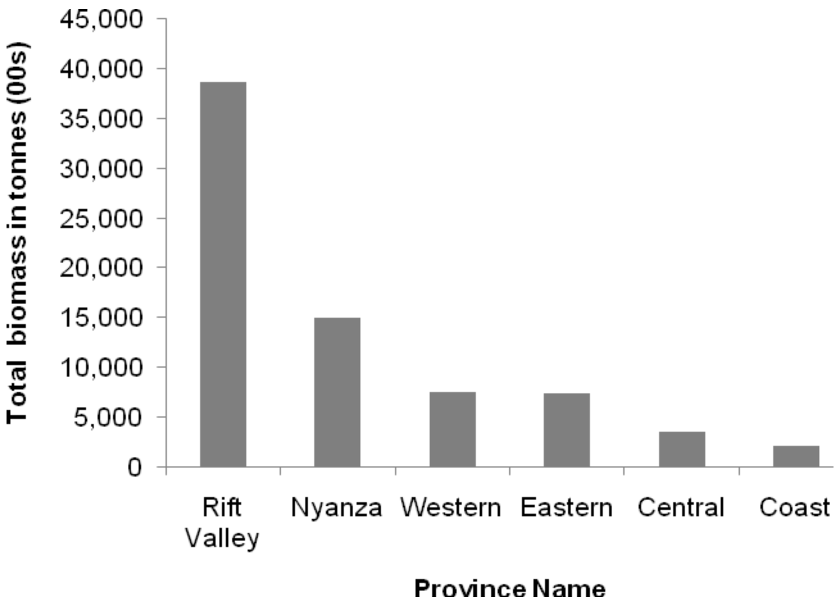

Figure 5 Total residue production for each province in Kenya

4.1.3 Residue production from crops

In this section, the results of the residues generated from each crop at national, provincial and district levels are illustrated. The amount of crop residues generated by the various crops varies widely (Lal, 2005). For example, residue production from maize had the highest potential while the least potential was from rice (Figure 6.). This variation is mainly caused by the differences in crop area planted, specific crop residue generation and crop yields. It was also found that there were no residues for some crops in the different provinces (Table 6). This is due to the different climatic conditions experienced in the provinces and to some extent the effect of the assumptions considered in this study, especially during the aggregation process. Detailed results for the residue production for each crop in each district can be found in Appendix 3.

Maize

The total amount of residues generated from maize was about 5,681,200 tonnes. Maize stalks contributed the bulk of the residue generated from this crop (Table 6 and Appendix 3). Overall, maize residues constituted about 80% of the total residue generated in the country (Table 6). Rift Valley and Nyanza Provinces had the highest maize residue generation (Table 6). Amongst the districts, Trans Nzoia, Uasin Gishu and Nandi districts had the most maize residue production with 570,200, 505,800 and 364,300 tonnes respectively. Generally, maize was being produced in all the six provinces and constituted the bulk of the total residues generated in all the regions.

Wheat

There was a total residue production of approximately 416,000 tonnes from wheat. Wheat residue contributed about seven per cent of the total residue generated in Kenya. Similarly to maize, wheat residue production was more concentrated in Rift Valley Province which accounted for 79% of the total amount of residue in the country (Table 6). Narok and Uasin Gishu districts were the highest producers of this residue in the country with a residue generation of about 153,200 and 100,000 tonnes respectively.

Sugarcane

The amount of residues generated from sugarcane was around 1,184,400 tonnes. There was a higher generation from sugarcane tops and leaves than bagasse (Table 6). Sugarcane contributed only 11 % of the total residues and was produced from Rift Valley and Nyanza Provinces (Table 6). High residue yields from sugarcane were attained in Nyando, Nandi and Kericho districts and the amount of residue generated in these districts was 541,400, 380,300 and 254,900 tonnes respectively. Generally, there was very little sugarcane production in Kenya.

Rice

Rice generated a total residue of around 102,400 tonnes and there was more rice straw compared with rice husks (Table 6). Rice residues contributed the least to total residue produced in the nation with only 1.5% and this was mainly concentrated in Nyanza and Central Provinces (Table 6). Kirinyaga district was the main producer with 58,900 tonnes.

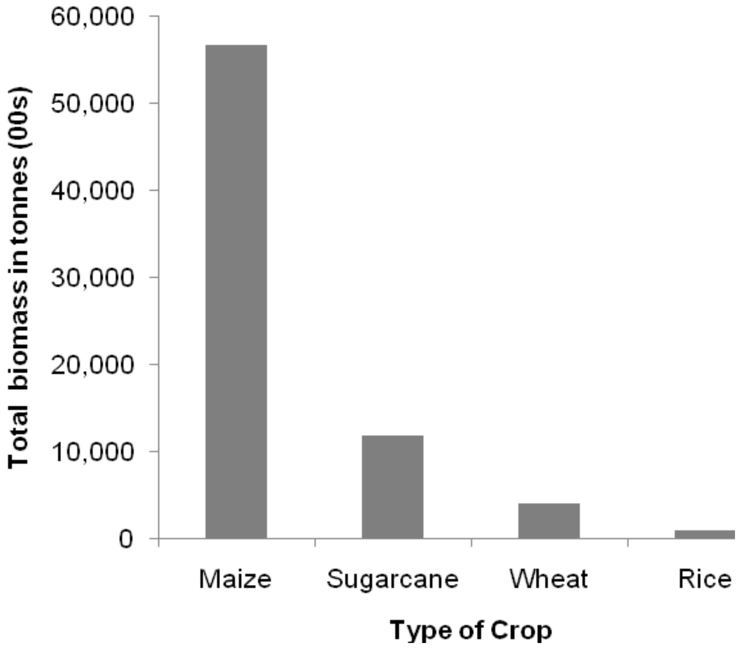

Figure 6 Total amount of crop residue produced from each crop in Kenya

Table 6 Total amount of crop residue generated for each crop type in each province in Kenya

Province name/crop residue	Maize stalk (tonnes)	Maize cobs (tonnes)	Rice husk (tonnes)	Rice straw (tonnes)	Wheat straw (tonnes)	Sugarcane Bagasse (tonnes)	Sugarcane tops and leaves (tonnes)
Rift Valley	2,465,400	436,200	-	-	328,800	221,400	414,200
Western	636,000	112,500	-	-	200	-	-
Nyanza	771,900	136,600	5,500	30,500	-	191,200	357,600
Central	225,900	40,000	9,000	50,000	18,000	-	-
Eastern	561,600	99,400	-		69,600	-	-
Coast	166,300	29,400	1,100	6,300	-	-	-

4.2 Energy potential of the estimated crop residues

The total amount of energy that can be generated from crop residues was around 124,300 TJ. It was apparent that high residue production yielded higher energy content. Like crop residue production, Rift Valley Province had the highest potential of around 64,800 TJ with the least potential coming from Coast Province with 3,500 TJ (Figure 7). Similarly, districts with a high residue production for each crop type had higher energy contents. Therefore, Nandi, Uasin Gishu, Trans Nzoia and Nyando had energy potentials of 11,400 TJ, 10700 TJ, 10200 TJ and 8000 TJ respectively (Tables 7 and 9).

Table 7 Total amount of energy that can be generated for each crop residue in each province in Kenya

Province name/Crop residue	Maize stalk (TJ)	Maize cobs (TJ)	Rice husk (TJ)	Rice straw (TJ)	Wheat straw (TJ)	Sugarcane bagasse (TJ)	Sugarcane tops and leaves (TJ)
Rift Valley	44,800	6,500	-	-	5,900	1,900	6,500
Western	11,600	1,700	-	-	-	-	-
Nyanza	14,000	2,000	80	500	-	1,600	5,700
Central	4,100	600	130	700	300	-	-
Eastern	10,200	1,500	-	-	1,300	-	-
Coast	3,000	400	20	90	-	-	-

In the case of the different crops, the trend was no different as maize residue topped the energy potential with rice having the least. The total energy potential for maize, sugarcane, wheat and rice was 100,400, 15,700, 7,500 and 1,520 TJ respectively.

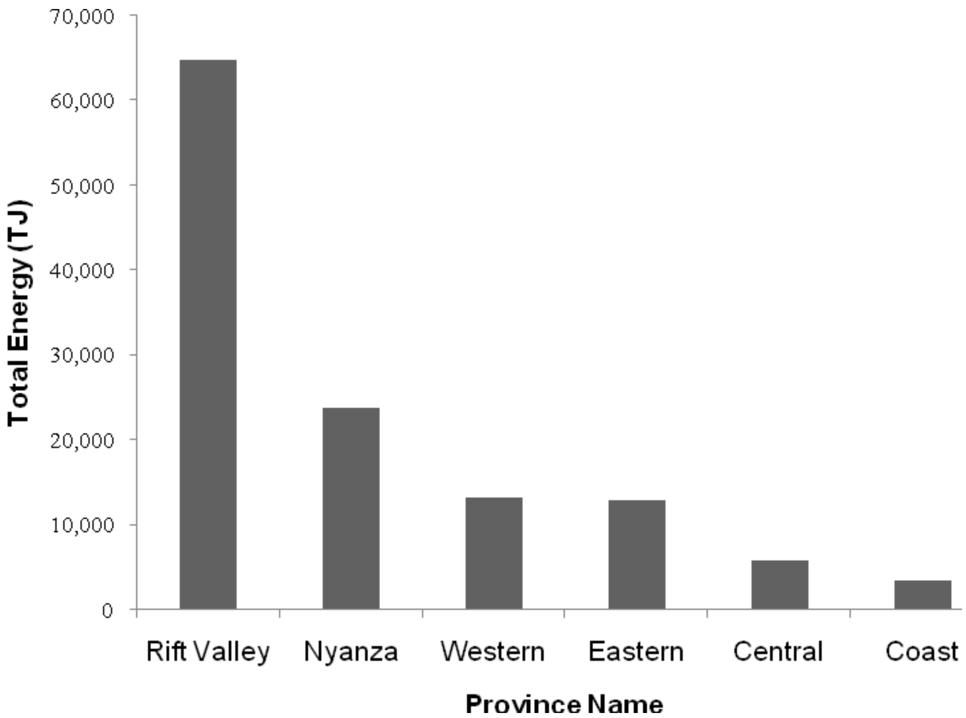

Figure 7 Total energy content estimated for each province in Kenya

4.3 GIS Model development

This section provides results from the GIS tool created for Rift Valley Province. Figure 1 (in Chapter 3) shows the location of this province in Kenya. Biomass supply was estimated for three crops: maize, wheat and sugarcane. Rice was not considered since findings from the land use dataset did not reveal any rice growing areas in the province. Results comprised GIS maps which illustrate the spatial distribution of crop residues generated in all the districts in the region. This has been illustrated for each crop type. In addition, a map showing the total energy potential that can be generated from all the crop residues in each district in the region has been presented. Lastly, potential sites for biomass power plants and the amount of crop residues that can be collected at different collection distances are presented.

4.3.1 Residue production from districts

The total amount of crop residue generated in the province was about 3,866,000 tonnes and was concentrated in the western sides. Nandi, Uasin Gishu, and Trans-Nzoia districts were amongst the main producers in the province (Figure. 8). They had a residue production potential of 744,740, 605,800 and 576,600 tonnes respectively (Table 8). High residue yields are a result of the high crop yields attained in these districts as well as higher numbers of cultivated crop areas (Table 5).

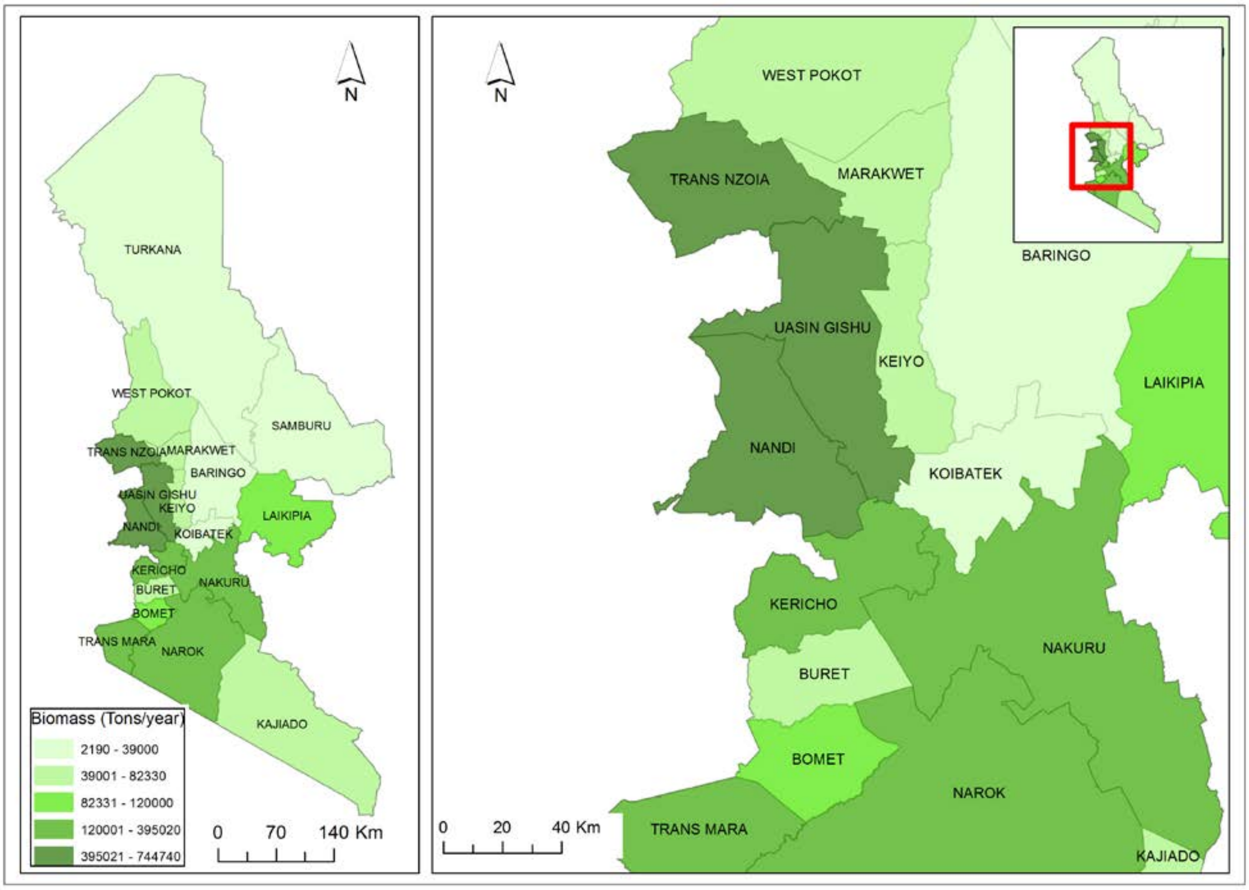

Figure 8 Total crop residue generated in each district in Rift Valley Province

Table 8 Total crop residues generated for each crop type in each district in Rift Valley Province

District name/crop residue	Maize stalk (tonnes)	Maize cob (tonnes)	Wheat straw (tonnes)	Sugarcane bagasse (tonnes)	Sugarcane tops and leaves (tonnes)
Uasin Gishu	429,800	76,000	100,000	4	10
Nandi	309,500	54,800	140	132,500	247,800
Trans Nzoia	484,500	85,700	6,400	-	-
Narok	144,500	25,600	153,200	-	-
Kericho	118,900	21,000	220	88,800	166,100
Nakuru	205,700	36,400	50,000	50	100
Trans Mara	230,600	40,800	-	-	-
Laikipia	91,800	16,200	12,000	-	-
Bomet	97,800	17,300	30	-	-
Kajiado	69,900	12,400	30	-	-
Buret	60,300	10,700	-	-	-
Marakwet	60,000	10,600	-	-	-
Keiyo	48,200	8,500	6,400	-	-
West Pokot	50,800	9,000	-	80	150
Koibatek	33,100	5,900	-	-	-
Baringo	26,400	4,700	-	-	-
Turkana	2,100	370	-	-	-
Samburu	1,500	270	420	-	-

4.3.2 Residue production from crops

Maize

The total amount of maize residue generated in the province was 2,901,600 tonnes. High residue production was achieved in Trans Nzoia, Uasin Gishu, Nandi, and Trans Mara districts as explained in Figure 9 and Table 8. These districts generated about 59% of the total maize residue in the province. Maize residue was generated in all the districts in the province and like total residue generation, maize production was also concentrated on the western part of the province.

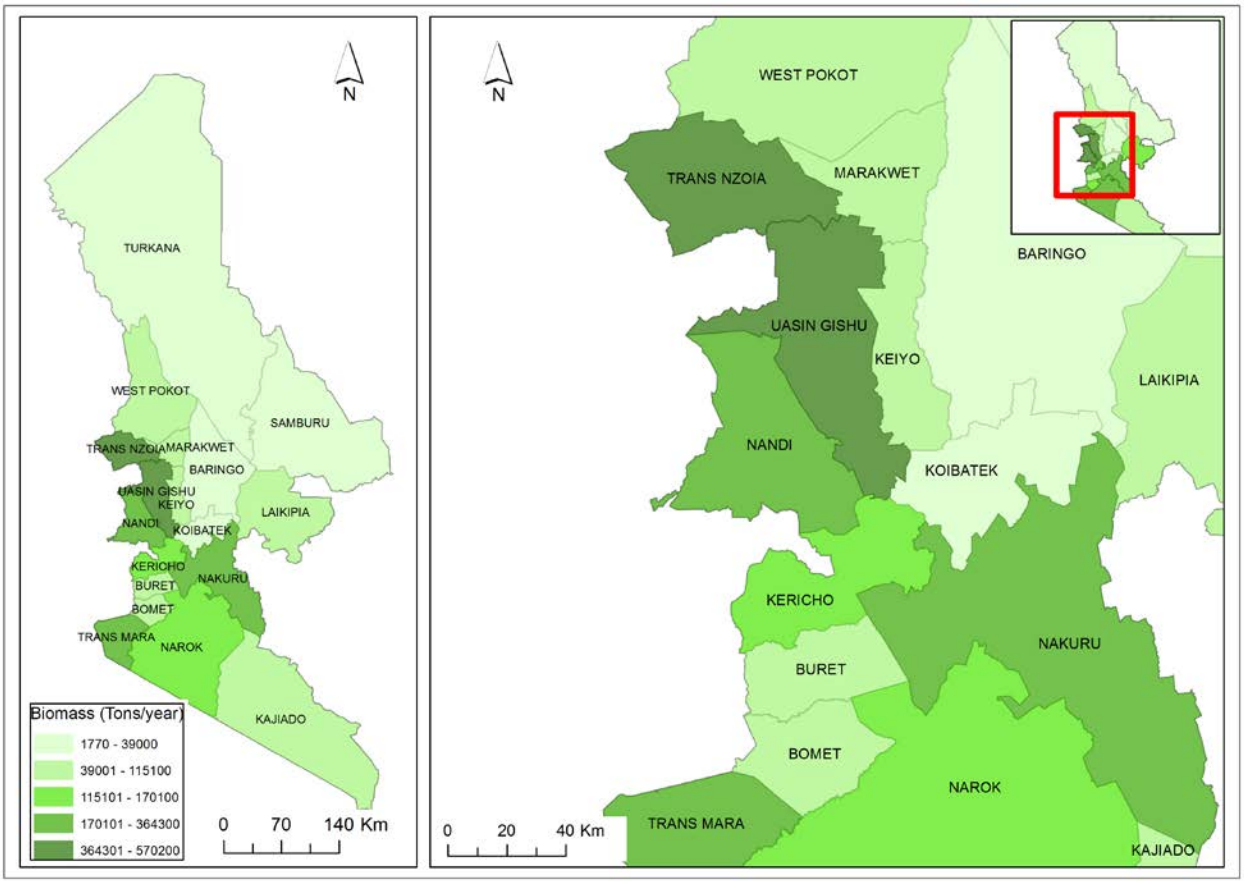

Figure 9 Total maize biomass production in each district in Rift Valley Province

Wheat

In the case of wheat, the total amount of residue produced was 328,800 tonnes. Districts with high production included Narok, and Uasin Gishu with a residue amount of 153,200 and 100,000 tonnes (Figure 10 and Table 8) correspondingly. Wheat production is not practised in all the districts in the province.

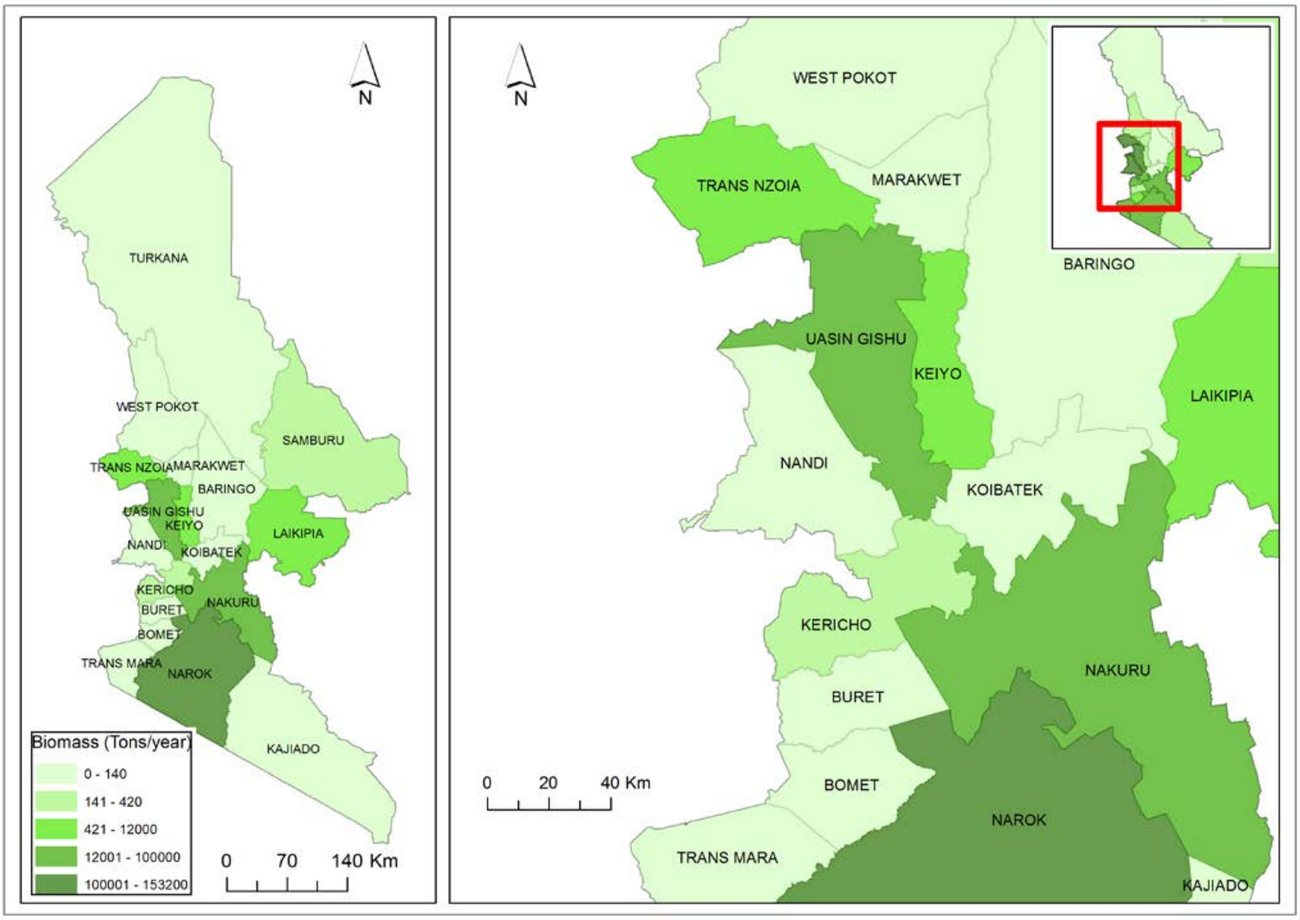

Figure 10 Total wheat residue production for each district in the Rift Valley Province

Sugarcane

Sugarcane is the least cultivated crop in the province with about 635,600 tonnes of residue generated from this crop. Districts with high production of this residue include Nandi and Kericho (Figure 11 and Table 8). According to the results, sugarcane only contributes 11% to the residue content in the province and is only cultivated in three districts; hence there is very little biomass potential from this crop.

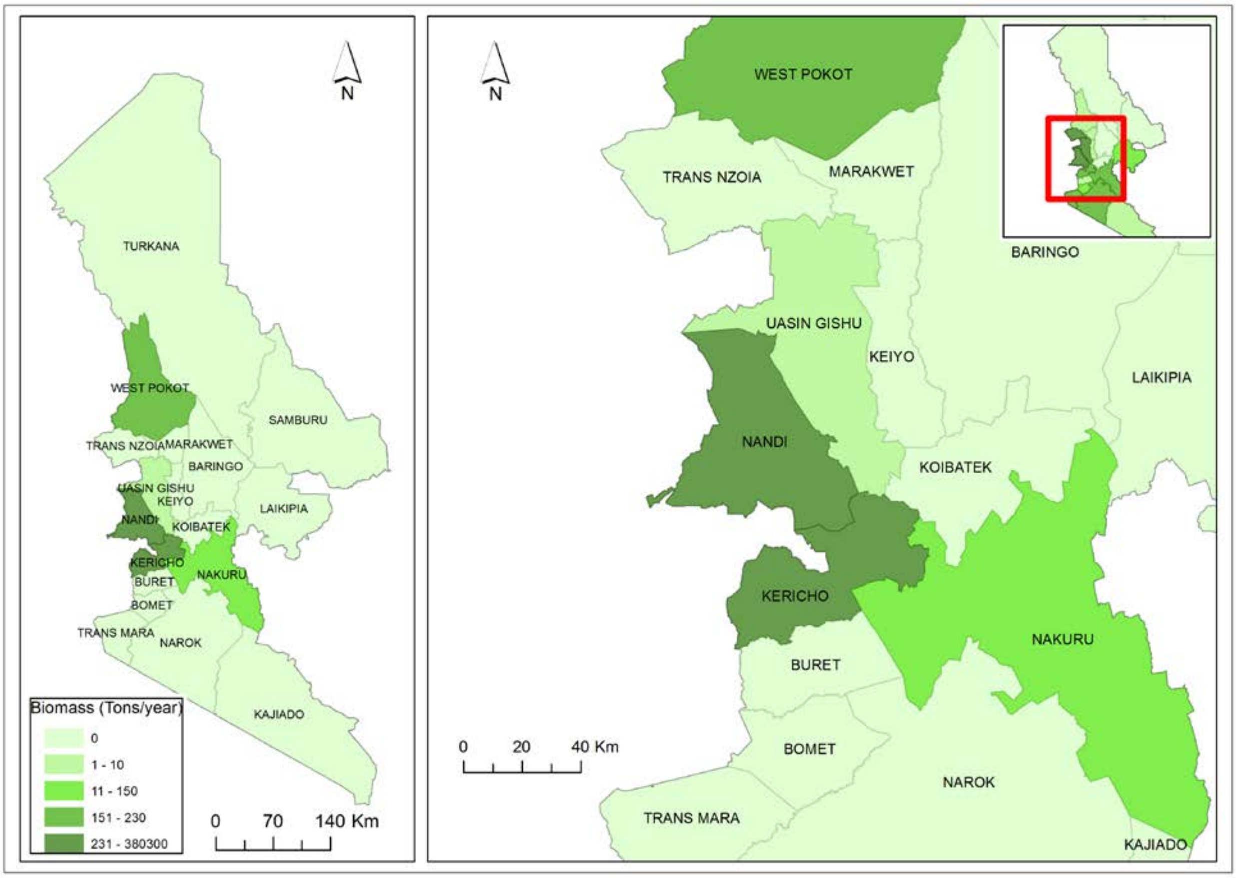

Figure 11 Total sugarcane residue production in each district in Rift Valley province

4.3.3 Total energy potential

The amount of energy that can be generated from crop residue biomass in this province was approximately 65,800 TJ. Nandi, Uasin Gishu and Trans Nzoia districts were the key energy producers with an energy potential of 11,400, 10,700 and 10,200 TJ respectively (Figure 12). Among the crops, maize had the highest energy potential in the province with 51,500 TJ, thereby contributing about 76% of the total energy that can be generated. The least potential was produced by wheat at 11%. Detailed results for each crop type in the district can be found in Table 9.

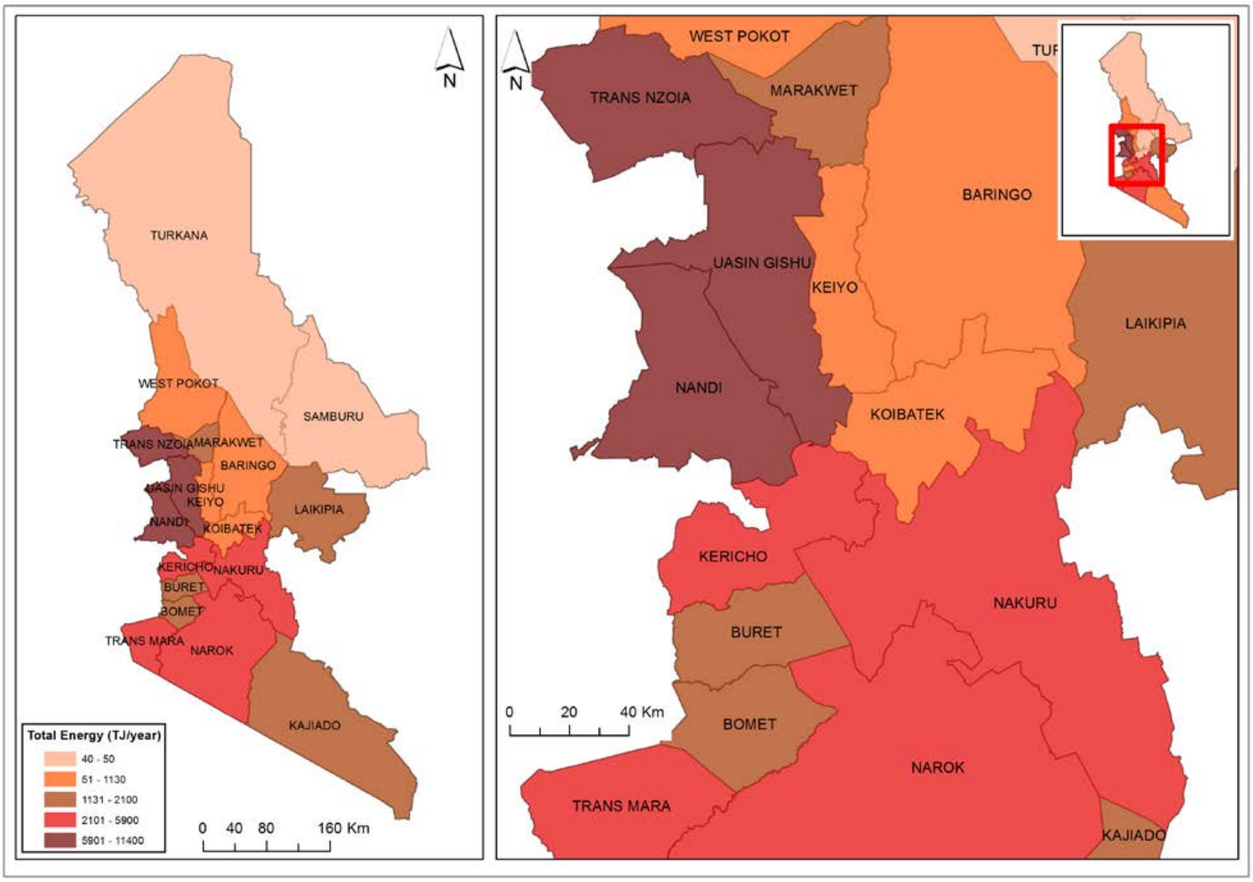

Figure 12 Total energy generated from all the crop types in each district in Rift Valley Province

Table 9 Total energy potential for each crop residue in each district in Rift Valley province

District name/crop residue	Maize stalk (TJ)	Maize cob (TJ)	Wheat straw (TJ)	Sugarcane bagasse (TJ)	Sugarcane tops and leaves (TJ)
Uasin Gishu	7,800	100	1,800	-	-
Nandi	5,600	800	-	1,100	3,900
Trans Nzoia	8,800	1,300	100	-	-
Narok	2,600	400	2,800	-	-
Kericho	2,200	300	-	800	2,600
Nakuru	3,700	500	900	-	-
Trans Mara	4,200	600	-	-	-
Laikipia	1,700	200	200	-	-
Bomet	1,800	300	-	-	-
Kajiado	1,300	190	-	-	-
Buret	1,200	160	-	-	-
Marakwet	1,200	160	-	-	-
Keiyo	900	130	100	-	-
West Pokot	900	140	-	-	-
Koibatek	600	90	-	-	-
Baringo	500	70	-	-	-
Turkana	40	10	-	-	-
Samburu	30	4	10	-	-

4.3.4 Potential sites for biomass power plants

Seven possible locations of biomass plants were in areas near to, or on the road network and where a high residue amount could be collected at a radius of about 10 – 20 km as shown in Figure 13 to illustrate the usefulness of this tool. In addition, the amount of crop residue biomass that can be collected with an increase in buffer distance is illustrated using two radii (10 and 20 km) and is displayed in Figure 14. For these scenarios, Trans Nzoia district had the highest residue amount of 156,840 tonnes at a buffer distance of 20km. Very little residue was available at a distance of 10 km.

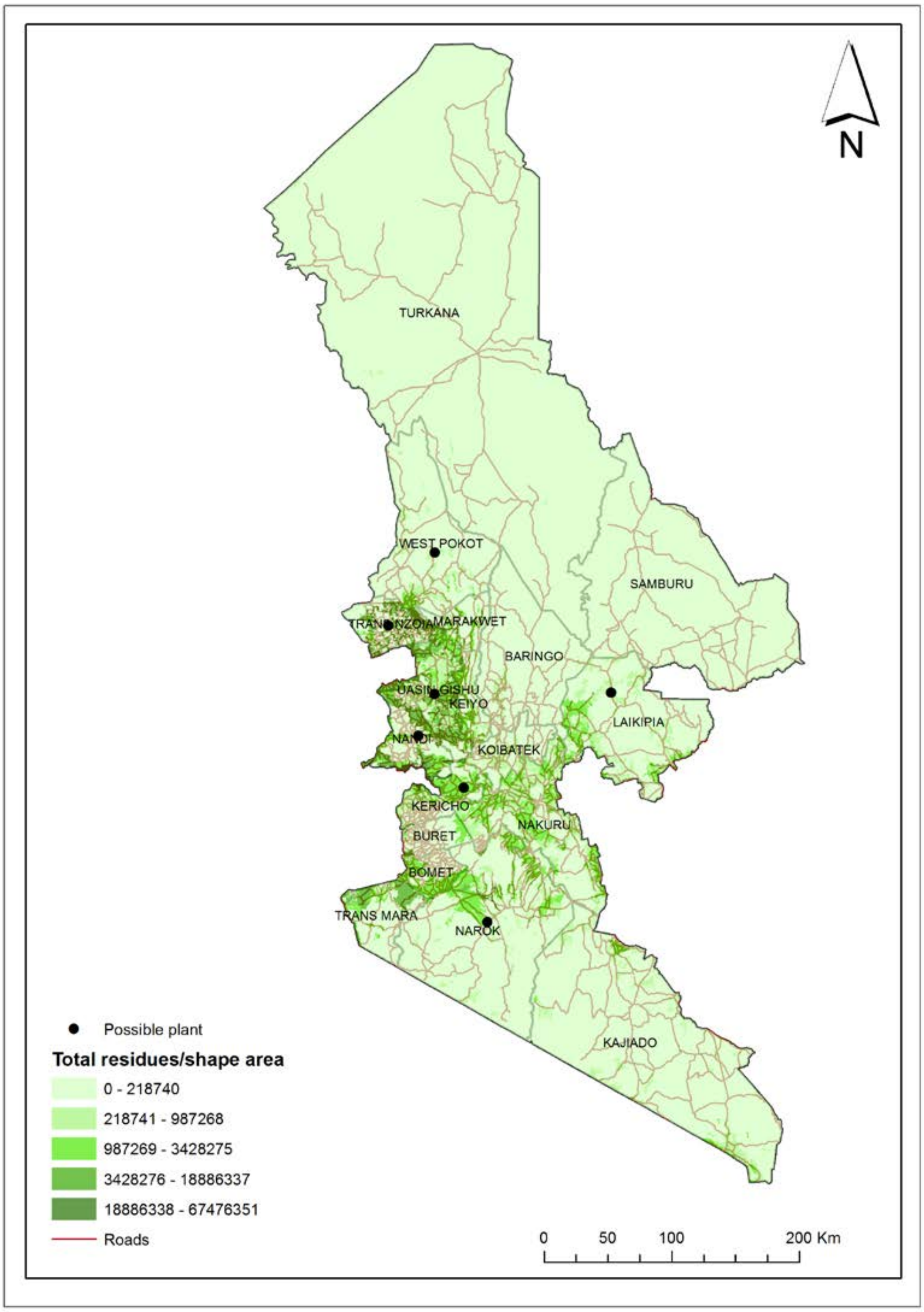

Figure 13 Potential locations for biomass plants in Rift Valley Province for a selected number of districts

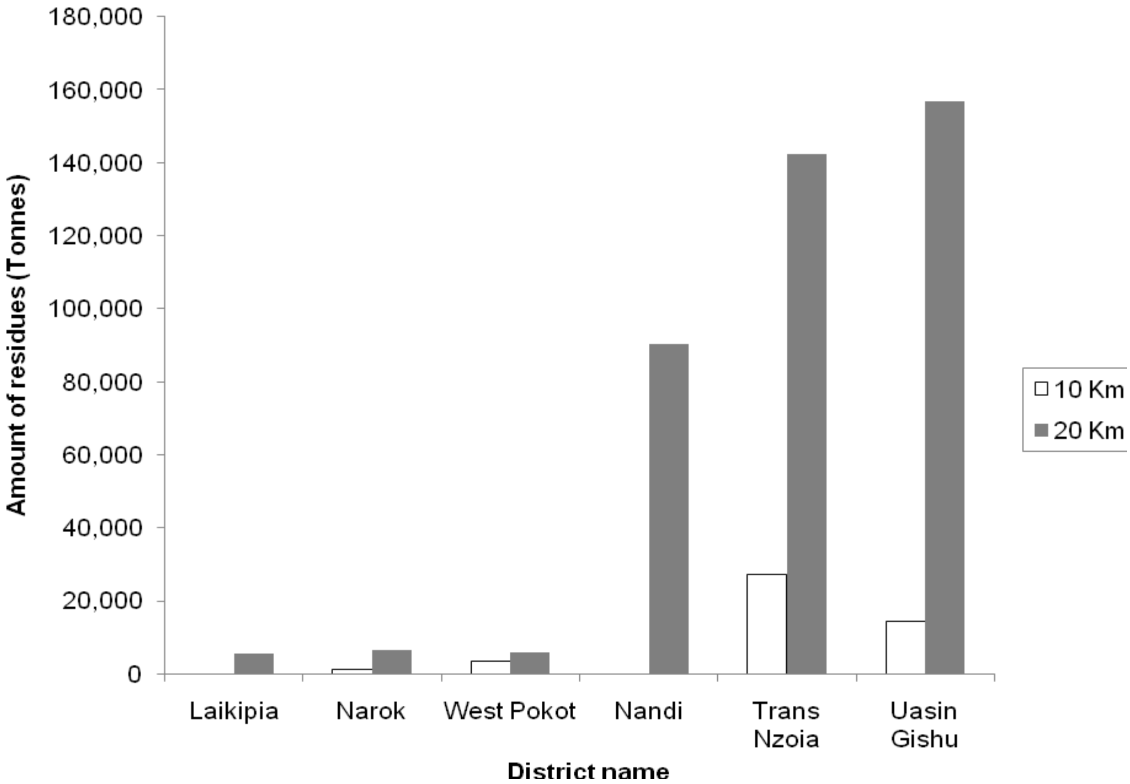

Figure 14 Amount of biomass residue available at 10 km and 20 km buffer radii for Laikipia, Narok, West Pokot, Nandi, Trans Nzoia and Uasin Gishu districts

Chapter 5 Discussion and Conclusion

This study estimated the amount of crop residues and their energy potential from six provinces in Kenya: Rift Valley, Western, Nyanza, Eastern, Central and Coast, utilising a GIS based approach. For each of the provinces, crop residues were assessed at district level using residue to crop ratios. Crops selected in the study were maize, wheat, rice and sugarcane. The residues estimated were maize stalks, maize cobs, rice husks, rice straw, sugarcane bagasse and sugarcane tops and leaves. In addition, a GIS tool that automates the process of crop residue estimation and identifies potential sites for biomass plants was created using ArcGIS extension Model Builder with Rift Valley Province as a case study.

5.1 Crop residue and their energy potential

The total amount of crop residues generated in Kenya was about 7.4 million tonnes with a total energy potential of about 124,300 TJ (Tables 6 and 7). This result is different from figures reported in earlier studies. For instance, Cooper and Laing (2007) reported a total crop residue amount of about 5.2 million tonnes and an energy potential of about 64,000 TJ being generated in Kenya, while Senelwa and Hall (1993) as cited in Wamukonya and Jenkins (1995) reported a figure of about 11 million tonnes. This variation is due to differences in the main approach utilised, the number and combination of crops evaluated and crop residue characteristics, such as residue to product ratios and moisture content utilised. For example, in the present study, four crops were chosen, while in Cooper and Laing's (2007) research; only three crops were considered. In addition, this study has utilised a GIS approach while previous studies were non-GIS based. Furthermore, different crop residues have different characteristics which affect the amount of residues that can be generated and their respective energy potential (Tables 1 and 2). Lastly, in this study, a cropland map had to be created for the residue assessment to be carried out and results from this map might have caused the variations in the amount of residues. An advantage of a GIS based model is that changes in datasets and or assumptions can quickly be incorporated and new analyses completed.

However, variations in crop residue estimates for one nation from different studies have been reported. For example, in the US, a wide range of crop residue estimates has been presented (Lal, 2005). Moreover, the selection of crops for evaluation was consistent with previous studies and residues from maize, wheat, rice and sugarcane have been considered (Eisentraut, 2010; Jingura & Matengaifa, 2008; Scarlat et al., 2010). Additionally, the scale for conducting the study was consistent with earlier studies, residue estimation being conducted at regional level (Shi et al., 2008; Singh et al., 2011).

There was a high production from maize residues of about 5.2 million tonnes followed by sugarcane, then wheat and lastly rice residues (Figure 6). This is consistent with Cooper and Laing's (2007) study where about 4.4 million tonnes were generated from maize with rice generating the least amount of crop residues. The difference in residue generation among crops results from the variation in the residue to crop ratios and the size of the area cultivated or harvested. In Kenya, maize is the main food crop planted by all the households and this has resulted in a higher area cultivated under this crop than other crops (Table 5).

Amongst the provinces, Rift Valley had the highest residue generation and energy potential compared to other provinces (Figures 5 and 7). The total amount of crop residues generated in this province was about 3,866,000 million tonnes with an energy potential of about 65,800 TJ. This high capability is because this region achieves high agricultural yields and has a huge agricultural sector. This is consistent with other studies where regions with high agricultural production and acreage resulted in higher residue yields (Scarlat et al., 2010). At district level, high residue and energy potentials were achieved in Nandi, Uasin Gishu and Trans Nzoia which are located in Rift Valley Province.

5.2 A GIS tool for residue assessment

In addition, this study presents a GIS tool that automates the process of estimating the crop residues at regional level in Kenya. It also identifies potential locations of biomass plants. Potential sites for these plants were located in areas near or on the road network and where a sufficient amount of residue can be collected at a given distance to sustain their operation. A buffer distance of 20km was found to be ideal as the amount of residue collected is sufficient to sustain a plant. For the selected number of districts, the highest residue was achieved in Uasin Gishu district with the residue amount of 156,800 tonnes at a distance of 20km. This information has been lacking in most GIS studies assessing the potential of crop residues for energy generation (Milbrandt, 2009; Singh et al., 2011; Voivontas et al., 2001). However, with the implementation of the new constitution in the near future, which assigns 47 counties to be the main administrative boundaries in Kenya, the GIS tool created will not used in its original form. This model will have to be fed new input data on both the administrative and landuse data and rerun again.

5.3 Spatial distribution of crop residues

This study identifies the spatial distribution of crop residues in Kenya and potential sites for bioenergy plants. This is the first time this type of research has been carried out in Kenya and this information is lacking in most African nations. It will provide information to decision makers on areas with high residue potential and might result in the implementation of the biomass conversion technologies, hence clean energy to the rural households.

5.4 Limitations of this study

There were several weaknesses in the approach utilised in this analysis. These included the inaccuracy in the resultant cropland map created and the Residue to Product ratios utilised in the analysis. Crop residue assessments have been conducted in various nations but the actual ratios are very hard to obtain making the estimation process a very complicated exercise. There is a need for an accurate cropland map of Kenya and specific Residue to Product Ratios to ensure precise biomass residues results are obtained in the future.

5.5 Future potential

This study concludes that there is a high potential in crop residues for energy generation in Kenya. It also concludes that the estimates of crop residues in this research are not precise and hence should be handled with care. However, there is a chance of perfection and the causes of inaccuracies and the implications for potential work have been provided.

In this project, only residues from four popular crops in Kenya were considered. Based on this there are chances that the biomass available in Kenya has been underestimated. In addition, biomass from other resources such as forestry and forestry related industries as well as animal and municipal waste which is generated in huge amounts in the country has not been considered. A GIS model should be developed that incorporates all of these biomass resources.

This study provides the theoretical amount of crop residues that can be generated in Kenya. It was also evident that large amounts of crop residues generated were field residues mainly from maize stalks (Table 6). However, only a fraction can be gathered for energy production. This is because agricultural crop residues are essential in sustaining soil quality, guarding the soil from erosion and retaining soil organic matter and mineral nutrients in the soil as well as maintaining water retention (Nelson, 2002) . In addition, these residues are used for other purposes in the rural areas, for example animal feeding. There is therefore need for an assessment to be conducted to determine the actual amount of residues that can be utilised for energy generation in Kenya. There have been various assumptions on the amount of residues that can be left in the field for erosion control and a though investigation should be conducted to determine the exact amount that can be applied in the Kenyan scenario. In addition, more information needs to be identified on the current actual uses of the residues before it can be known how much can be utilised for bioenergy.

Further, in this study only potential sites of biomass plants were identified. In order for development of these systems to be implemented in Kenya, optimal sites should be identified to enable decision makers make advanced decisions in the bioenergy sector. This was beyond the scope of this study.

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Appendices

Appendix 1A Allocation of user labels to the four crop types

USERLABEL	CROPTYPE	% POLYGON AREA
GDZ-r	Rice	1
GRZ-r	Rice	1
HD4	Wheat	1
HD4-mz	Maize	1
HD4-w	Wheat	1
HD57	Sugarcane	1
HD57-s	Sugarcane	1
HL4	Wheat	1
HL4-w	Wheat	1
HM4	Maize	1
HM4-mz	Maize	1
HM57	Sugarcane	1
HM57-s	Sugarcane	1
HR4	Maize	1
HR4-mz	Maize	1
HR57	Sugarcane	1
GRZ-r/4H(CP)FF	Rice	0.6
GRZ-r/4HCF	Rice	0.6
HD4/2H(CP)78	Wheat	0.6
HD4/2SP6	Wheat	0.6
HD4/2TO28	Wheat	0.6
HD4/HR14/2H(CP)78	Wheat	0.6
HD4/SR247V	Wheat	0.6
HD4-w/2H(CP)8	Wheat	0.6
HD4-w/2WP6	Wheat	0.6
HL4/2H(CP)78	Wheat	0.6
HL4/2H(CP)8	Wheat	0.6
HL4/2TP8	Wheat	0.6
HM4/2H(CP)78	Maize	0.6
HM4/2H(CP)8	Maize	0.6

HM4/2SOJ67	Maize	0.6
HM4/2SVJ67	Maize	0.6
HM4/2TC8	Maize	0.6
HM4/2TO28	Maize	0.6
HM4/2TV28	Maize	0.6
HM4/2WP6	Maize	0.6
HM4/HR14/2WP6	Maize	0.6
HM4/HR24	Maize	0.6
HM4/TR247V	Maize	0.6
HM4-mz/2H(CP)78	Maize	0.6
HM4-mz/2TP8	Maize	0.6
HM4-mz/2WP6	Maize	0.6
HM4-mz/HR14/2H(CP)78	Maize	0.6
HM4-w/2H(CP)8	Wheat	0.6
HM57/2WP6	Sugarcane	0.6
HR4/2H(CP)	Maize	0.6
HR4/2H(CP)78	Maize	0.6
HR4/2H(CP)78/SR247V	Maize	0.6
HR4/2H(CP)8	Maize	0.6
HR4/2SOJ67	Maize	0.6
HR4/2SP6	Maize	0.6
HR4/2SV6	Maize	0.6
HR4/2SVJ67	Maize	0.6
HR4/2TC8	Maize	0.6
HR4/2TO268	Maize	0.6
HR4/2TO28	Maize	0.6
HR4/2TP8	Maize	0.6
HR4/2TV268	Maize	0.6
HR4/2TV28	Maize	0.6
HR4/2WC7	Maize	0.6
HR4/2WP6	Maize	0.6
HR4/5U	Maize	0.6
HR4/5UR	Maize	0.6
HR4/HM14	Maize	0.6
HR4/SR147V	Maize	0.6
HR4/SR23H47V	Maize	0.6

HR4/SR247V	Maize	0.6
HR4/SR3H47V	Maize	0.6
HR4/TM13H47V	Maize	0.6
HR4/TR13H47V	Maize	0.6
HR4/TR13S47V	Maize	0.6
HR4/TR147V	Maize	0.6
HR4-mz/2H(CP)78	Maize	0.6
HR4-mz/2SVJ67	Maize	0.6
HR4-mz/2TP8	Maize	0.6
HR4-mz/2WP6	Maize	0.6
HR4-mz/TR247V	Maize	0.6
HR57-s/HR14	Sugarcane	0.6
HR57-s/HR24	Sugarcane	0.6
2TV28/HR4	Maize	0.4
HR4/2H(CP)78/SR247V	Maize	0.4
HR4/2TP8/SR247V	Maize	0.4
HR4/2WP6/SR247V	Maize	0.4
HR4/SR147V/2TO28	Maize	0.4
HR4/SR147V/2TP8	Maize	0.4
HR4/SR23H47V/2H(CP)78	Maize	0.4
HR4/SR23H47V/2TV8	Maize	0.4
HR4/SR247V/2TO28	Maize	0.4
HR4/SR3H47V/2TV8	Maize	0.4
HR4/TR13H47V/2TP8	Maize	0.4
2H(CP)/HR14	Maize	0.15
2H(CP)/HR24	Maize	0.15
2H(CP)78/HD14-w	Wheat	0.15
2H(CP)78/HM24	Maize	0.15
2H(CP)78/HR14	Maize	0.15
2H(CP)78/HR24	Maize	0.15
2H(CP)78/HR24-mz	Maize	0.15
2H(CP)8/HM14	Maize	0.15
2H(CP)8/HM24	Maize	0.15
2H(CP)8/HR14	Maize	0.15
2H(CP)8/HR14/2TP8	Maize	0.15
2H(CP)8/HR24	Maize	0.15

2SCJ/HR24	Maize	0.15
2SOJ67/HD14	Wheat	0.15
2SOJ67/HM14	Maize	0.15
2SOJ67/HM24	Maize	0.15
2SOJ67/HR14	Maize	0.15
2SOJ67/HR24	Maize	0.15
2SP6/HR14	Maize	0.15
2SP6/HR24	Maize	0.15
2SV6/HR14	Maize	0.15
2SV6/HR24	Maize	0.15
2SVJ67/HD14	Wheat	0.15
2SVJ67/HM14	Maize	0.15
2SVJ67/HM24	Maize	0.15
2SVJ67/HR14	Maize	0.15
2SVJ67/HR24	Maize	0.15
2TC8/HM14	Maize	0.15
2TC8/HM24	Maize	0.15
2TC8/HR14	Maize	0.15
2TC8/HR24	Maize	0.15
2TO268/HR14	Maize	0.15
2TO268/HR24	Maize	0.15
2TO28/HR14	Maize	0.15
2TO28/HR14/SR247V	Maize	0.15
2TO28/HR24	Maize	0.15
2TP8/HM14	Maize	0.15
2TP8/HM24	Maize	0.15
2TP8/HR14	Maize	0.15
2TP8/HR14/SR247V	Maize	0.15
2TP8/HR14-mz	Maize	0.15
2TP8/HR24	Maize	0.15
2TV268/HR14	Maize	0.15
2TV268/HR24	Maize	0.15
2TV28/HR14	Maize	0.15
2TV28/HR24	Maize	0.15
2TV8/HR24	Maize	0.15
2WC7/HM14	Maize	0.15

2WC7/HR14	Maize	0.15
2WC7/HR24	Maize	0.15
2WP6/HM14	Maize	0.15
2WP6/HM14-mz	Maize	0.15
2WP6/HM24	Maize	0.15
2WP6/HM24-mz	Maize	0.15
2WP6/HR14	Maize	0.15
2WP6/HR14/SR247V	Maize	0.15
2WP6/HR14-mz	Maize	0.15
2WP6/HR24	Maize	0.15
2WP6/HR24-mz	Maize	0.15
4H(CP)F8/HR14	Maize	0.15
4H(CP)F8/HR24	Maize	0.15
5U/HR14	Maize	0.15
5UR/HR14	Maize	0.15

Appendix 1B The ‘legend’ file for Kenya

LCCCode	LCCLevel	LCCOwnLabel	LCCOwnDescr	LCCLabel	MapCode
10153-1-W7	A1XXB5XXD1D9-A7A9-W7	TBE47PL	Forest Plantation, Broad Leaved Evergreen, Rainfed Permanent	Permanently Cropped Area With Rainfed Tree Crop(s) Crop Cover: (Plantation(s))	TBE47PL
10154-11341-W7	A1B1B5XXD1D9-B3-W7	TL47PL	Trees Plantation - Large Fields, Rainfed Permanent	Permanently Cropped Area With Rainfed Tree Crop(s) Crop Cover: (Plantation(s))	TL47PL
10176-W8	A1B2B5XXD1D9-W8	TR47V	Rainfed Tree Crop, Small Fields	Permanently Cropped Area With Small Sized Field(s) Of Rainfed Tree Crop(s) Crop Cover: Orchard(s)	TR47V
10180-W8	A1B2B6XXD1D9-W8	TR147V	Rainfed Tree Crop, Clustered Small Fields	Permanently Cropped Area With Scattered Clustered Small Sized Field(s) Of Rainfed Tree Crop(s) Crop Cover: Orchard(s)	TR147V
10184-W8	A1B2B7XXD1D9-W8	TR247V	Rainfed Tree Crop, Isolated Small Fields	Permanently Cropped Area With Scattered Isolated Small Sized Field(s) Of Rainfed Tree Crop(s) Crop Cover: Orchard(s)	TR247V
10223-11341	A3B1B5XXD1-B3	HL4	Rainfed Herbaceous - Large Fields	Rainfed Herbaceous Crop(s)	HL4
10223-11971	A3B1B5XXD1-B4	HM4	Rainfed Herbaceous - Medium Fields	Rainfed Herbaceous Crop(s)	HM4
10655-13227-S13Zs2	A3B1B5C1D3D9-D4-S13Zs2	HD57-s	Irrigated Herbaceous Crop, Large to Medium Fields - Sugarcane	Permanently Cropped Area With Surface Irrigated Herbaceous Crop(s) Dominant Crop: Other Food Crops - Sugar Cane	HD57-s
10243-11971	A3B1B6XXD1-B4	HM14	Rainfed Herbaceous - Clustered Medium Fields	Scattered Clustered Field(s) Of Rainfed Herbaceous Crop(s)	HM14
10263-11971	A3B1B7XXD1-B4	HM24	Rainfed Herbaceous - Isolated Medium Fields	Scattered Isolated Field(s) Of Rainfed Herbaceous Crop(s)	HM24
10282	A3B2B5XXD1	HR4	Continuos Rainfed Small fields [cereal]	Small Sized Field(s) Of Rainfed Herbaceous Crop(s)	HR4

10290-13227	A3B2B5XXD3D9-D4	HR57	Herbaceous - Small Fields, Irrigated Surface Permanent	Permanently Cropped Area With Small Sized Field(s) Of Surface Irrigated Herbaceous Crop(s)	HR57
10292	A3B2B6XXD1	HR14	Rainfed Herbaceous - Clustered Small Fields	Scattered Clustered Small Sized Field(s) Of Rainfed Herbaceous Crop(s)	HR14
10302	A3B2B7XXD1	HR24	Rainfed Herbaceous - Isolated Small Fields	Scattered Isolated Small Sized Field(s) Of Rainfed Herbaceous Crop(s)	HR24
10494-5671-W7	A1XXB5C1D1D9-A8A9-W7	TNE47PL	Needle Leaved Evergreen Forest Plantation	Permanently Cropped Area With Rainfed Needleleaved Evergreen Tree Crop(s) Crop Cover: (Plantation(s))	TNE47PL
10499-1888-S0606W8	A1B1B5C1D3D9-A7A9D4-S0606W8	TBED57V-cc	Irrigated Orchard, Large to Medium Fields - Citrus	Permanently Cropped Area With Surface Irrigated Broadleaved Evergreen Tree Crop(s) Dominant Crop: Fruits & Nuts - Citrus Fruits (Citrus spp.) Crop Cover: Orchard(s)	TBED57V-cc
10519-11997-W8	A1B1B6C2D1D9-B4C3C7C17-W8	TM13H47V	Rainfed Tree Crop (1 add. Herbaceous Crop) - Clustered Medium Fields	Permanently Cropped Area With Scattered Clustered Field(s) Of Rainfed Tree Crop(s) (One Additional Crop) (Herbaceous Terrestrial Crop With Simultaneous Period) . Crop Cover: Orchard(s)	TM13H47V
10545-12626-W8	A1B2B5C2D1D9-C3C7C17-W8	TR3H47V	Rainfed Tree Crop (1 add. Herbaceous Crop), Small Fields	Permanently Cropped Area With Small Sized Field(s) Of Rainfed Tree Crop(s) (One Additional Crop) (Herbaceous Terrestrial Crop With Simultaneous Period) . Crop Cover: Orchard(s)	TR3H47V
10553-12614-W8	A1B2B6C2D1D9-C3C6C17-W8	TR13S47V	Rainfed Tree Crop (1 add. Shrubs Crop), Clustered Small Fields	Permanently Cropped Area With Scattered Clustered Small Sized Field(s) Of Rainfed Tree Crop(s)	TR13S47V

				(One Additional Crop) (Shrub Crop With Simultaneous Period) . Crop Cover: Orchard(s)	
10553-12626-W8	A1B2B6C2D1D9-C3C7C17-W8	TR13H47V	Rainfed Tree Crop (1 add. Herbaceous Crop), Clustered Small Fields	Permanently Cropped Area With Scattered Clustered Small Sized Field(s) Of Rainfed Tree Crop(s) (One Additional Crop) (Herbaceous Terrestrial Crop With Simultaneous Period) . Crop Cover: Orchard(s)	TR13H47V
10613-W8	A2B2B5C1D1D9-W8	SR47V	Permanently Cropped Area With Small Sized Field(s) Of Rainfed Shrub Crop(s) Crop Cover: (Orchard(s))	Permanently Cropped Area With Small Sized Field(s) Of Rainfed Shrub Crop(s) Crop Cover: (Orchard(s))	SR47V
10637	A3B1B5C1D1	HD4	Large-Medium Fields, Rainfed	Rainfed Herbaceous Crop(s)	HD4
10637-11341-S311	A3B1B5C1D1-B3-S311	HL4-w	Large Fields - Wheat, Rainfed	Rainfed Herbaceous Crop(s) Dominant Crop: Cereals - Wheat (Triticum spp.)	HL4-w
10637-11971-S0305	A3B1B5C1D1-B4-S0305	HM4-mz	Herbaceous - Medium Fields -Maize, Rainfed	Rainfed Herbaceous Crop(s) Dominant Crop: Cereals - Maize (Zea mays L.)	HM4-mz
10637-11971-S311	A3B1B5C1D1-B4-S311	HM4-w	Herbaceous - Medium Fields -Wheat, Rainfed	Rainfed Herbaceous Crop(s) Dominant Crop: Cereals - Wheat (Triticum spp.)	HM4-w
10637-S0305	A3B1B5C1D1-S0305	HD4-mz	Large-Medium Fields - Maize, Rainfed	Rainfed Herbaceous Crop(s) Dominant Crop: Cereals - Maize (Zea mays L.)	HD4-mz
10637-S0913	A3B1B5C1D1-S0913	HD4-z	Large-Medium Fields - Sisal, Rainfed	Rainfed Herbaceous Crop(s) Dominant Crop: Industrial Crops - Sisal (Agave spp.)	HD4-z
10637-S311	A3B1B5C1D1-S311	HD4-w	Large-Medium Fields - Wheat, Rainfed	Rainfed Herbaceous Crop(s) Dominant Crop: Cereals - Wheat	HD4-w

				(Triticum spp.)	
10655	A3B1B5C1D3D9	HD57	Herbaceous - Large to Medium Fields, Irrigated Surface Permanent	Permanently Cropped Area With Irrigated Herbaceous Crop(s)	HD57
10655-12598	A3B1B5C1D3D9-B4D4	HM57	Herbaceous - Medium Fields, Irrigated Surface Permanent	Permanently Cropped Area With Surface Irrigated Herbaceous Crop(s)	HM57
10655-12598-S13Zs2	A3B1B5C1D3D9-B4D4-S13Zs2	HM57-s	Herbaceous - Medium Fields, Sugar Cane Irrigated Surface Permanent	Permanently Cropped Area With Surface Irrigated Herbaceous Crop(s) Dominant Crop: Other Food Crops - Sugar Cane	HM57-s
10677	A3B1B6C1D1	HD14	Clustered Large-Medium Fields, Rainfed	Scattered Clustered Field(s) Of Rainfed Herbaceous Crop(s)	HD14
10677-11341	A3B1B6C1D1-B3	HL14	Clustered Large Fields, Rainfed	Scattered Clustered Field(s) Of Rainfed Herbaceous Crop(s)	HL14
10677-11971-S0305	A3B1B6C1D1-B4-S0305	HM14-mz	Rainfed Herbaceous - Clustered Medium Fields, Maize Rainfed	Scattered Clustered Field(s) Of Rainfed Herbaceous Crop(s) Dominant Crop: Cereals - Maize (Zea mays L.)	HM14-mz
10677-S311	A3B1B6C1D1-S311	HD14-w	Clustered Large-Medium Fields, Wheat Rainfed	Scattered Clustered Field(s) Of Rainfed Herbaceous Crop(s) Dominant Crop: Cereals - Wheat (Triticum spp.)	HD14-w
10717-11971-S0305	A3B1B7C1D1-B4-S0305	HM24-mz	Rainfed Herbaceous - Isolated Medium Fields, Maize	Scattered Isolated Field(s) Of Rainfed Herbaceous Crop(s) Dominant Crop: Cereals - Maize (Zea mays L.)	HM24-mz
10756-S0305	A3B2B5C1D1-S0305	HR4-mz	Herbaceous - Small Fields - Maize, Rainfed	Small Sized Field(s) Of Rainfed Herbaceous Crop(s) Dominant Crop: Cereals - Maize (Zea mays L.)	HR4-mz
10765-13227-S13Zs2	A3B2B5C1D3D9-D4-S13Zs2	HR57-s	Herbaceous - Small Fields, Sugar Cane	Permanently Cropped Area With Small Sized Field(s) Of Surface	HR57-s

			Irrigated Surface Permanent	Irrigated Herbaceous Crop(s) Dominant Crop: Other Food Crops - Sugar Cane	
10776-S0305	A3B2B6C1D1-S0305	HR14-mz	Herbaceous - Clustered Small Fields - Maize, Rainfed	Scattered Clustered Small Sized Field(s) Of Rainfed Herbaceous Crop(s) Dominant Crop: Cereals - Maize (Zea mays L.)	HR14-mz
10796-S0305	A3B2B7C1D1-S0305	HR24-mz	Herbaceous - Isolated Small Fields - Maize, Rainfed	Scattered Isolated Small Sized Field(s) Of Rainfed Herbaceous Crop(s) Dominant Crop: Cereals - Maize (Zea mays L.)	HR24-mz
20019-12374	A4A10B3C1-B14	2SCJ	Closed shrubs	Continuous Closed Medium To High Shrubland (Thicket)	2SCJ
21455	A2A20B4C1	2H(CP)	Closed to very open herbaceous	Continuous Closed to Very Open Herbaceous Vegetation	2H(CP)
20389	A4A11B3C1XXXXF2F4F7G4	2SP6	Open general shrubs with closed to open herbaceous	Shrubland with Herbaceous	2SP6
20060-6022	A2A14B4C3-A15	2HR	Sparse herbaceous	Parklike Patches Of Sparse ((20-10) - 4%) Herbaceous Vegetation	2HR
20553-121340(1)[Z1]	A1A10B1C1D1E2F2F5F10G2-G6Z1	2WC27Y	Closed woody (broadleaved deciduous) with sparse trees	Broadleaved Deciduous Closed Woody Vegetation With Medium High Emergents	2WC27Y
20268	A1A10B1C1XXXXF2F5F10G2	2WC7	Closed woody with sparse trees	Closed Woody Vegetation With Emergents	2WC7
20286	A3A10B2C1XXXXF2F6F7G3	2TC8	Closed trees with shrubs	Forest With Shrubs	2TC8
20304	A1A11B1C1XXXXF2F4F7G4	2WP6	Open general woody with herbaceous	Open Woody Vegetation With Herbaceous Layer	2WP6
20326	A3A11B2C1XXXXF2F6F7G3	2TP8	Open general trees with shrubs	Woodland With Shrubs	2TP8
20361-12374	A4A10B3C1XXXXF2F5F10G2-B14	2SCJ7	Closed shrubs with sparse trees	Medium To High Thicket With Emergents	2SCJ7

20389-3012	A4A11B3C1XXXXF2F4F7G4-A13	2SV6	Very open shrubs with closed to open herbaceous	(40 - (20-10)%) Shrubland with Herbaceous	2SV6
20391-3719	A4A11B3C1XXXXF2F4F7G4F2F5F10G2-A13B14G11	2SVJ67	Very open shrubs with closed to open herbaceous and sparse trees	(40 - (20-10)%) Medium To High Shrubland With Medium to Tall Herbaceous And Emergents	2SVJ67
20391-701	A4A11B3C1XXXXF2F4F7G4F2F5F10G2-A12B14F9G11	2SOJ67	Open shrubs with closed to open herbaceous and sparse trees	((70-60) - 40%) Medium To High Shrubland With Open Medium to Tall Herbaceous And Emergents	2SOJ67
20637-52949	A3A10B2C1D1E1F2F5F7G2F2F5F10G2-B5F9G6G5	2TCI177	Closed multilayered trees (broadleaved evergreen)	Multi-Layered Broadleaved Evergreen High Forest (With Second Layer Of Medium High Trees) With Emergents	2TCI177
20862-1	A3A11B2C1D1E2F2F6F7G3-A12	2TO28	Open trees (broadleaved deciduous) with closed to open shrubs	Broadleaved Deciduous ((70-60) - 40%) Woodland With Shrubs	2TO28
20326-3012	A3A11B2C1XXXXF2F6F7G3-A13	2TV8	Very open trees with closed to open shrubs	(40 - (20-10)%) Woodland With Shrubs	2TV8
20862-3012	A3A11B2C1D1E2F2F6F7G3-A13	2TV28	Very open trees (broadleaved deciduous) with closed to open shrubs	Broadleaved Deciduous (40 - (20-10)%) Woodland With Shrubs	2TV28
20868-3011	A3A11B2C1D1E2F2F4F7G4F2F6F10G3-A12F9	2TO268	Open trees (broadleaved deciduous) with closed to open herbaceous and sparse shrubs	Broadleaved Deciduous ((70-60) - 40%) Woodland With Open Herbaceous Layer And Sparse Shrubs	2TO268
20868-3012	A3A11B2C1D1E2F2F4F7G4F2F6F10G3-A13	2TV268	Very open trees (broadleaved deciduous) with closed to open herbaceous and sparse shrubs	Broadleaved Deciduous (40 - (20-10)%) Woodland With Herbaceous Layer And Sparse Shrubs	2TV268
3026-S0308	A1B1B5C1-S0308	GDZ-r	Graminoids - Large to	Continuous Large To Medium	GDZ-r

			Medium Fields - Rice	Sized Field(s) Of Graminoid Crops On Permanently Flooded Land Dominant Crop: Cereals - Rice (Oryza spp.)	
3043-S0308	A1B2B5C1-S0308	GRZ-r	Cereals, Rice - Small Fields	Continuous Small Sized Field(s) Of Graminoid Crops On Permanently Flooded Land Dominant Crop: Cereals - Rice (Oryza spp.)	GRZ-r
21647	A2A20B4C1XXXXF2F5F10G2F2F6F10G3	2H(CP)78	Closed to very open herbaceous with sparse trees and shrubs	Closed To Very Open Herbaceous Vegetation with Trees and Shrubs	2H(CP)78
21648	A2A20B4C1XXXXF2F6F10G3	2H(CP)8	Closed to very open herbaceous with sparse shrubs	Closed To Very Open Herbaceous Vegetation with Shrubs	2H(CP)8
20512	A4A14B3C3XXXXF2F4F10G4	2SR6	Sparse shrubs with sparse herbaceous	Sparse Shrubs and Sparse Herbaceous	2SR6
42347-R1	A2A20B4C1-R1	4H(CP)FF	Closed to Open Herbaceous On Permanently Flooded Land	Closed to Open Herbaceous Vegetation On Permanently Flooded Land Water Quality: Fresh Water	4H(CP)FF
40056-R1	A2A12B4C2-R1	4HCF	Closed herbaceous on temporarily flooded land - fresh water	Closed Herbaceous Vegetation On Temporarily Flooded Land Water Quality: Fresh	4HCF
42178-R1	A2A20B4C2XXXXF2F6F10G3-R1	4H(CP)F8	Closed to very open herbaceous with sparse shrubs on temporarily flooded land - fresh water	Closed to Very Open Herbaceous Vegetation With Sparse Shrubs On Temporarily Flooded Land . Water Quality: Fresh Water	4H(CP)F8
40371	A4A13B3C2XXXXF2F4F7G4	4SPF6	Open general shrubs with closed to open herbaceous on temporarily flooded land	Open Shrubs With Herbaceous Vegetation On Temporarily Flooded Land	4SPF6
40344-4999-R1	A3A13B2C2XXXXF2F4F7G4-F8-R1	4TPF6	Open general trees with	Woodland With Closed	4TPF6

			closed to open herbaceous on temporarily flooded land - fresh water	Herbaceous Vegetation On Temporarily Flooded Land Water Quality: Fresh	
40113-R2	A3A12B2C1D1E1-R2	4TCFF1Y	Closed trees (broadleaved evergreen) on permanently flooded land - brackish water	Broadleaved Evergreen Forest On Permanently Flooded Land Water Quality: Brackish	4TCFF1Y
40332-R1	A1A13B1C2XXXXF2F4F7G4-R1	4WPF6	Open general woody with closed to open herbaceous on temporarily flooded land - fresh water	Open Woody Vegetation With Herbaceous Vegetation On Temporarily Flooded Land Water Quality: Fresh	4WPF6
5003--A21	A4-A21	5A	Airport	Non-Linear Built Up Area(s) Built-up object: Airport	5A
5003-8	A4-A12	5I	Industrial area - general	Industrial And/Or Other Area(s)	5I
5003-9	A4-A13	5U	Urban areas (general)	Urban Area(s)	5U
5003-9--A34	A4-A13-A34	5UC	Refugee camp	Urban Area(s) Built-up object: Refugee Camp	5UC
5003-9--A44Zp1	A4-A13-A44Zp1	5UR	Rural settlements	Urban Area(s) Built-up object: Other - Rural Settlement	5UR
5004-2	A2-A6	5Q	Quarry	Extraction Site(s)	5Q
6002-1	A3-A7	6R	Bare rock	Bare Rock(s)	6R
6005	A5	6S	Bare soil	Bare Soil And/Or Other Unconsolidated Material(s)	6S
6006	A6	6L	Sand	Loose And Shifting Sands	6L
7002-5	A1B1-A5	7WP	Artificial Lakes or Reservoirs	Artificial Perennial Waterbodies (Standing)	7WP
7002-5(3)[Z9]	A1B1-A5Z9	7WP-Y	Fish Pond	Artificial Perennial Waterbodies (Standing)	7WP-Y
8002-1-V1	A1B1-A4-V1	8WFP	River	Perennial Natural Waterbodies (Flowing) Salinity: Fresh, < 1000 ppm of TDS	8WFP

8002-5-V1	A1B1-A5-V1	8WP	Natural lakes	Perennial Natural Waterbodies (Standing) Salinity: Fresh, < 1000 ppm of TDS	8WP
8003-4	A1B2-A4B6	8WFN1	River banks	Non-Perennial Natural Waterbodies (Flowing) (Surface Aspect: Sand)	8WFN1
8003-7	A1B2-A5B5	8WN2	Lake shore	Non-Perennial Natural Waterbodies (Standing) (Surface Aspect: Bare Soil)	8WN2
8004-19	A1B3-B6	8WT1	Sand beaches	Tidal Area (Surface Aspect: Sand)	8WT1
8006	A2B1	8SP	Snow	Perennial Snow	8SP
20007-Zt1	A3A10B2C1-Zt1	2TC-B	Closed Trees - Bamboo	Continuous Closed Trees Floristic Aspect: Bamboo	2TC-B
10241-11968	A3B1B5XXD3D9-B3D4	HL57	Irrigated Herbaceous Crop, Large Fields	Permanently Cropped Area With Surface Irrigated Herbaceous Crop(s)	HL57
10567-11341-S0619W8	A2B1B5C1D1D9-B3-S0619W8	SL47V-p	Rainfed Shrub Crop, Large Fields - Pineapple	Permanently Cropped Area With Rainfed Shrub Crop(s) Dominant Crop: Fruits & Nuts - Pineapple (Ananas comosus (L.) Merr.) Crop Cover: Orchard(s)	SL47V-p
10567-11341-S0804W8	A2B1B5C1D1D9-B3-S0804W8	SL47V-t	Rainfed Shrub Crop, Large Fields - Tea	Permanently Cropped Area With Rainfed Shrub Crop(s) Dominant Crop: Beverage - Tea (Camellia sinensis (L.) O.K.) Crop Cover: Orchard(s)	SL47V-t
10567-11341-W8	A2B1B5C1D1D9-B3-W8	SL47V	Rainfed Shrub Crop, Large Fields	Permanently Cropped Area With Rainfed Shrub Crop(s) Crop Cover: Orchard(s)	SL47V
10567-11341-S0802W8	A2B1B5C1D1D9-B3-S0802W8	SL47V-c	Rainfed Shrub Crop, Large Fields - Coffee	Permanently Cropped Area With Rainfed Shrub Crop(s) Dominant Crop: Beverage - Coffee (Coffea ssp.)	SL47V-c

				Crop Cover: Orchard(s)	
10613-S0802W8	A2B2B5C1D1D9-S0802W8	SR47V-c	Rainfed Shrub Crop, Small Fields - Coffee	Permanently Cropped Area With Small Sized Field(s) Of Rainfed Shrub Crop(s) Dominant Crop: Beverage - Coffee (Coffea ssp.) Crop Cover: Orchard(s)	SR47V-c
10613-S0804W8	A2B2B5C1D1D9-S0804W8	SR47V-t	Rainfed Shrub Crop, Small Fields - Tea	Permanently Cropped Area With Small Sized Field(s) Of Rainfed Shrub Crop(s) Dominant Crop: Beverage - Tea (Camellia sinensis (L.) O.K.) Crop Cover: Orchard(s)	SR47V-t
10621-S0804W8	A2B2B6C1D1D9-S0804W8	SR147V-t	Rainfed Shrub Crop, Clustured Small Field - Tea	Permanently Cropped Area With Scattered Clustered Small Sized Field(s) Of Rainfed Shrub Crop(s) Dominant Crop: Beverage - Tea (Camellia sinensis (L.) O.K.) Crop Cover: Orchard(s)	SR147V-t
10215-W8	A2B2B6XXD1D9-W8	SR147V	Rainfed Shrub Crop, Clustered Small Fields	Permanently Cropped Area With Scattered Clustered Small Sized Field(s) Of Rainfed Shrub Crop(s) Crop Cover: Orchard(s)	SR147V
10621-S0802W8	A2B2B6C1D1D9-S0802W8	SR147V-c	Rainfed Shrub Crop, Clustered Small Fields - Coffee	Permanently Cropped Area With Scattered Clustered Small Sized Field(s) Of Rainfed Shrub Crop(s) Dominant Crop: Beverage - Coffee (Coffea ssp.) Crop Cover: Orchard(s)	SR147V-c
10219-W8	A2B2B7XXD1D9-W8	SR247V	Rainfed Shrub Crop, Isolated Small Fields	Permanently Cropped Area With Scattered Isolated Small Sized Field(s) Of Rainfed Shrub Crop(s)	SR247V

				Crop Cover: Orchard(s)	
10629-S0804W8	A2B2B7C1D1D9-S0804W8	SR247V-t	Rainfed Shrub Crop, Isolated Small Fields - Tea	Permanently Cropped Area With Scattered Isolated Small Sized Field(s) Of Rainfed Shrub Crop(s) Dominant Crop: Beverage - Tea (Camellia sinensis (L.) O.K.) Crop Cover: Orchard(s)	SR247V-t

Appendix 2 Crop yields per hectare for each district in Rift Valley province

	Average crop production per hectare		
District name/Crop type	**Maize**	**Wheat**	**Sugarcane**
Baringo	0.72	0.00	0.00
Bomet	1.95	0.00	0.00
Buret	9.07	0.00	0.00
Kajiado	1.54	0.03	0.00
Keiyo	1.32	6.38	0.00
Kericho	1.87	0.16	146.84
Koibatek	0.56	0.00	0.00
Laikipia	1.14	1.59	0.00
Marakwet	4.01	0.00	0.00
Nakuru	1.19	0.67	0.10
Nandi	4.11	0.01	68.49
Narok	2.37	1.56	0.00
Samburu	0.12	0.51	0.00
Turkana	1.20	0.00	0.00
Trans Mara	4.69	0.00	0.00
Trans Nzoia	6.44	0.12	0.00
Uasin Gishu	3.92	1.33	4.17
West Pokot	1.65	0.00	1.29

Appendix 3 Crop residue yields per district

District name/ Crop residue	Maize stalk (tonnes)	Maize cobs (tonnes)	Rice husk (tonnes)	Rice straw (tonnes)	Wheat straw (tonnes)	Sugarcane Bagasse (tonnes)	Sugarcane tops and leaves (tonnes)
Bungoma	239544	42378	-	-	-	-	-
Busia	49174	8700	-	-	-	-	-
Butere/Mumias	37208	6583	-	-	-	-	-
Kakamega	71274	12610	-	-	-	-	-
Lugari	113590	20096	-	-	60	-	-
Mt Elgon	71927	12726	-	-	181	-	-
Teso	12326	2181	-	-	-	-	-
Vihiga	40942	7245	-	-	-	-	-
Bondo	30352	5370	34	189	-	-	-
Gucha	97709	17282	-	-	-	-	-
Homa Bay	74228	13133	-	-	-	-	-
Kisii Central	92592	16382	-	-	-	-	-
Kisumu	23960	4239	1561	8709	-	2595	4852
Kuria	34976	6189	-	-	-	-	-
Migori	85977	15211	-	-	-	-	-
Nyamira	170093	30087	-	-	-	-	-
Nyando	29521	5223	2535	14144	-	188630	352732
Rachuonyo	47651	8431	-	-	-	-	-
Siaya	68579	12133	1338	7464	-	-	-
Suba	16285	2881	-	-	-	-	-
Kiambu	33249	5883	-	-	-	-	-
Kirinyaga	25428	4499	8954	49960	-	-	-
Maragua	14069	2489	-	-	-	-	-
Muranga	26257	4646	-	-	-	-	-
Nyandarua	42740	7562	-	-	6486	-	-
Nyeri	30292	5359	-	-	11531	-	-

Thika	53866	9530	-	-	-		-
Marsabit	940	166	-	-	-	-	-
Moyale	515	91	-	-	-	-	-
Isiolo	478	84	-	-	-	-	-
Meru North	143310	25355	-	-	-	-	-
Meru Central	55210	9768	-	-	69630	-	-
Meru South	29162	5160	-	-	-	-	-
Tharaka	18144	3210	-	-	-	-	-
Mbeere	33353	5901	-	-	-	-	-
Embu	39859	7052	-	-	-	-	-
Kitui	42248	7475	-	-	-	-	-
Machakos	114331	20228	-	-	-	-	-
Mwingi	29094	5147	-	-	-	-	-
Makueni	54933	9719	-	-	-	-	-
Kwale	39744	7032	-	-	-	-	-
Taita Taveta	17005	3009	555	-	-	-	-
Lamu	33008	5841	-	-	-	-	-
Malindi	28661	5071	-	-	-	-	-
Kilifi	36752	6502	-	-	-	-	-
Mombasa	787	139	-	-	-	-	-
Tana River	10388	1838	568	3167	-	-	-